PRODUCTION OF POWER BY MEANS OF WIND-DRIVEN GENERATOR

HEARING

BEFORE THE

COMMITTEE ON INTERIOR AND INSULAR AFFAIRS HOUSE OF REPRESENTATIVES

EIGHTY-SECOND CONGRESS

FIRST SESSION

ON

H. R. 4286

A BILL AUTHORIZING INVESTIGATION, RESEARCH, AND DEVELOPMENT WORK BY THE SECRETARY OF THE INTERIOR AND THE CONSTRUCTION AND OPERATION OF FACILITIES, INCLUDING NOT MORE THAN ONE DEMONSTRATION PLANT, TO DETERMINE AND DEMONSTRATE THE ECONOMIC FEASIBILITY OF PRODUCING ELECTRIC POWER AND ENERGY BY MEANS OF A WIND-DRIVEN GENERATOR OPERATED IN CONJUNCTION WITH AN ELECTRIC POWER SYSTEM, AND FOR OTHER PURPOSES

SEPTEMBER 19, 1951

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PRODUCTION OF POWER BY MEANS OF WIND-DRIVEN GENERATOR

WEDNESDAY, SEPTEMBER 19, 1951

HOUSE OF REPRESENTATIVES,
COMMITTEE ON INTERIOR AND INSULAR AFFAIRS,
Washington, D. C.

The committee met at 10 a. m., Hon. John R. Murdock (chairman) presiding.

The CHAIRMAN. Now, although this is a crowded time, in the closing hours of this first session of the Eighty-second Congress, I feel that this committee should give attention to the matter that we will take up next.

I have chosen to bring before the committee H. R. 4286, a bill which would authorize research in the field of generation of electric power from wind-driven generators. I believe one's ordinary reaction would be—why this type of legislation should come up at this time when for centuries man has been trying to develop power from the wind. There are certain reasons why I believe that the committee should consider this legislation and I wish to enumerate them briefly before we call upon the Assistant Secretary of the Interior, Mr. Warne, to officially open the testimony.

First, the requirements of national defense behoove all of us to find ways to aid in our defense program and one of the real problems for our scattered defense plants in remote areas is finding a suitable supply of electric power. It may be possible, after a small amount of research, to find ways to develop electric power from the wind, especially in those isolated western areas where certain sources of power are not easily provided.

Another reason for bringing this up is the continued drought in the Southwest. It seems logical that this method of generating electric power could be combined with hydroelectric power plants to save water when the wind is blowing and the power can be generated from that source. That would enable us to hold back precious water supplies which sometimes are not put to their maximum use because they have to be released in order to meet the requirements of the power load.

The third reason which prompted my bringing this matter up at this time is the information I have received that Mr. Percy Thomas has patented a means of changing the magnetic field on the wind-driven generator so that a constant output of power can be attained. You may not know that the wind is always going in gusts and is never steady, although it might appear to be a steady flow, and many earlier attempts to harness wind power have failed because the output was not constant. We are fortunate to have Mr. Thomas among the witnesses who will be called today and he will no doubt bring out this

point more in detail, but, to reiterate, I have decided to bring this matter to your attention first because of its possible service to the defense program, and, secondly, because the continued drought in the Southwest prompts us to explore every conceivable way of conserving water, and, third, that recent inventions are encouraging as far as wind-driven electric generators are concerned.

I might add to that, when this matter was first called to my attention, I spoke to Judge Morris, the chairman of the Indian Affairs Subcommittee, saying to him if there is any place where wind generators can be made available I think it will be on the great Navajo Reservation in three of the Western States. It was that thing that I stressed, Judge Morris, at first, and it is continually in my mind.

You recall, Judge, that I said our rehabilitation program contemplates a number of wells and the use of the ordinary windmills for pumping on the Navajo Reservation, that instead of 20 wells they should have 200 wells, and I did not know that that would suffice. That is what our hearings led us to believe before your committee some weeks ago.

Mr. MORRIS. Mr. Chairman, may I just use a moment of your time to suggest to you I received a number of letters recently from the Navajos in regard to this very matter that you mentioned. They are desperately, I would say, in need of wells, and desperately, of course, in need of water, wherever they might be able to get it, whether it is surface water or underground water. That is really their primary concern, and primary need, and if there is any feasible, reasonable way whatsoever to enhance their water supply it is definitely our duty to set the matter to work.

(H. R. 4286 and the reports of the Department of the Interior and Federal Power Commission are as follows:)

[H. R. 4286, 82d Cong., 1st sess.]

A BILL Authorizing investigation, research, and development work by the Secretary of the Interior and the construction and operation of facilities, including not more than one demonstration plant, to determine and demonstrate the economic feasibility of producing electric power and energy by means of a wind-driven generator operated in conjunction with an electric power system, and for other purposes

Be it enacted by the Senate and House of Representative of the United States of America in Congress assembled, That in order to promote the conservation of the natural resources of the Nation and to aid in the national defense, the Secretary of the Interior (hereinafter referred to as the Secretary) is authorized to construct, maintain, and operate facilities (including not more than one demonstration plant consisting of an aerogenerator of not to exceed ten thousand kilowatts capacity and related equipment) to determine and demonstrate the economic and engineering feasibility of commercially producing electric power and energy by means of a wind-driven generator when its operation is integrated with that of an electric power system.

SEC. 2. In order to carry out the purposes of this Act, the Secretary is authorized—

(a) to conduct investigation, research, and development work and to determine the best plant locations, designs, and conditions of operation;

(b) to locate, construct, and operate such demonstration plant on or in the vicinity of a Federal project having an electric power system, now or hereafter constructed, and to interconnect and integrate the operation of such demonstration plant with the electric power system of such Federal project;

(c) to withdraw public lands from entry and to acquire, by purchase, license, lease, or donation, secret processes, technical data, inventions, patent applications, patents, licenses, land and any interest in land and other property or rights;

(d) to engage, by contract or otherwise, engineers, architects, and such other personnel as may be deemed necessary, and any educational institution, scientific organization, or industrial or engineering firm deemed suitable to do any part of the investigation or other work;

(e) to cooperate with any other Federal or State department, agency, or instrumentality, and with any private person, firm, educational institution, or other organization in effectuating the purposes of this Act;

(f) to request other Federal departments, agencies, and instrumentalities to provide assistance in carrying out his functions under this Act, which assistance such departments, agencies, and instrumentalities are hereby authorized to render, and to advance to them funds required to render such assistance or to reimburse them for costs incurred in so doing; and

(g) to grant, on such terms as he may consider appropriate, licenses under patent rights acquired under this Act: *Provided*, That such licenses are consistent with the terms of the agreements by which such patent rights are acquired. No patent acquired by the United States under this Act shall prevent any citizen of the United States or corporation created under the laws of the United States or any State thereof, from using any invention, discovery, or process covered by such patent or restrict such use by any such citizen or corporation, or be the basis of any claim against any such person or corporation on account of such use.

SEC. 3. During such period (hereinafter referred to as the experimental period) as the demonstration plant is being operated to determine its engineering and economic feasibility, the electric power and energy produced thereby shall be delivered into the power system of the Federal project with which the demonstration plant is integrated and the Secretary shall establish an appropriate basis for charges for such power and energy, which charges shall constitute a production expense of the Federal power system involved and appropriate transfer of funds shall be made periodically to the Treasury to the credit of miscellaneous receipts on account of such expense.

SEC. 4. At such times as the Secretary determines that the engineering and economic feasibility of the demonstration plant has been established, the experimental period shall terminate and the demonstration plant shall be transferred to and become a part of the power system of the Federal project with which it is then integrated, and thereafter the operation of the demonstration plant shall, as a feature of a Federal project, be governed by the organic law establishing such Federal project, and Acts amendatory thereof or supplementary thereto. The Secretary, upon the termination of the experimental period, shall make findings as to the part of the cost of the demonstration plant properly allocable to investigation, research, and development work. The balance of the cost of the demonstration plant shall be added to and become a part of the cost of the Federal project of which the demonstration plant is made a part.

SEC. 5. All moneys received for royalties and licenses under section 2 (g) of this Act shall be paid into the Treasury to the credit of miscellaneous receipts.

SEC. 6. The Secretary may issue rules and regulations to effectuate the purposes of this Act.

SEC. 7. There are authorized to be appropriated from any moneys in the Treasury not otherwise appropriated, such sums as the Congress may from time to time deem necessary to carry out the provisions of this Act.

DEPARTMENT OF THE INTERIOR,
OFFICE OF THE SECRETARY,
Washington 25, D. C., September 11, 1951.

HON. JOHN R. MURDOCK,
Chairman, Committee on Interior and Insular Affairs, House of Representatives, Washington 25, D. C.

MY DEAR MR. MURDOCK: I am glad to comply with your request for a report on H. R. 4286, a bill authorizing investigation, research, and development work by the Secretary of the Interior and the construction and operation of facilities, including not more than one demonstration plant, to determine and demonstrate the economic feasibility of producing electric power and energy by means of a wind-driven generator operated in conjunction with an electric power system, and for other purposes.

I recommend that this bill be enacted.

In brief, the draft of bill provides for investigation, research, and development work and the construction, maintenance and operation of one commercial-size demonstration plant to determine the economic and engineering feasibility of commercially producing electric power and energy by means of a wind-driven generator when its operation is integrated with that of a hydroelectric power system.

Upon enactment of H. R. 4286, a number of sites would be investigated in the western United States to determine the best location for the installation it would

authorize. After selecting the site, specific meteorological data will be obtained and aerodynamic characteristics of proposed design by wind tunnel tests on models will be made and preliminary designs and final cost estimates prepared.

In general, it may be said that electrical generation by wind power, when integrated with that of a hydro system, will assist in firming the hydro system and will greatly increase the firm power available from hydroelectric systems where water availability is limited. The aerogenerator, construction of which enactment of H. R. 4286 would authorize, would be operated by the Secretary of the Interior, as this bill provides, in conjunction with such a system.

The successful operation of a wind-driven generator in 1945 as a regular unit of the Central Vermont Public Service Corp. utility system gave great promise of the practicability of development of wind power on a relatively large commercial scale. This marked the first use of wind power on such a scale in the world. The wind-driven generator with a capacity of 1,250 kilowatts was located on a small mountain in Vermont called Grandpa's Knob. The project was finally abandoned after the success of it had been technically demonstrated because it would have cost the chief sponsor, the S. Morgan Smith Co., several hundred thousand dollars more to complete tests, eliminate minor weaknesses of design and to pioneer sale of such wind turbines on a financially sound basis. Also at that time the immediate prospective market did not exist. The company, therefore, reluctantly abandoned the project for financial reasons and not for lack of demonstrated success. It placed its patents in the public domain.

Considerable research and investigation, I may also note, are now underway or authorized in Great Britain to determine the possibilities of harnessing the winds of the coastal districts of the north and west of Great Britain on a commercial scale. These winds, which have a high annual energy content, present opportunities for feasible development of power which in the aggregate might equal or exceed the energy which can be obtained from the whole of the existing and potential water power resources of Great Britain.

A news dispatch dated November 9, 1950, from London, stated that experts of ten European countries were meeting there to discuss the technical and economic aspects of wind power in generating electricity. They were scheduled to compare experiences in research and draft plans for exchanging information to avoid duplication in research.

For nearly 8 years investigations on this subject by the Federal Power Commission, under the direction of Mr. Percy H. Thomas, were made in the United States and particular study was given to the development of designs for a wind-driven generator of substantial capacity. The results of these studies indicate that wind-driven generators of 5,000 to 7,500 kilowatt capacity or even more are practical.

While considerable valuable design and test experience data have been obtained to date, the final development of an economical and efficient aerogenerator of practical commercial size requires further research, special design and test. The power systems under the jurisdiction of this Department in the West are completely hydroelectric at the present time. Development of financially and technically feasible aerogenerators for use in such systems is practicable and quite desirable because there is no fuel cost involved in their operation. It now appears entirely reasonable to expect that, once specific designs are proved, substantial quantities of electric energy can be generated by this method and that this energy can be absorbed into a power system so as to utilize to the best advantage the energy of the wind. These wind-power plants would be used to furnish supplemental energy only, thereby greatly augmenting the firm energy available from hydro power plants only. The problem in almost all parts of the West is that there is an inadequate supply of water to meet the needs of the people. Therefore, supplemental supply of energy is a necessity and the most economical means of providing such supplemental energy to that produced by hydro plants should be adopted.

Although, as heretofore mentioned, there is great national and international interest in wind power, no private companies or public organizations in the United States other than the Federal Government are now in a position to continue actively in developing and constructing a prototype wind power plant of substantial capacity, even though such development as a supplemental power source is justified. The private companies and organizations participating in the Grandpa's Knob project have already performed a monumental service to the Nation in demonstrating the commercial practicability of wind power but have been unable to proceed further. It, therefore, devolves upon public agencies concerned to continue the development since it is in the public interest to do so. This Department, because of its particular and immediate need for electric energy to supplement its deficient hydro systems, is peculiarly in a position to justify

taking the lead in continuing and furthering the wind power development program proposed herein.

It is believed that the benefits to the particular project and area in which the equipment would be located would justify the cost. Not only will more firm energy be provided in power-short areas but such supplemental production is estimated to be more economical than supplies from other potential sources. Furthermore, it is believed that the revenues will fully repay the costs and may well provide some surplus. The benefits to the entire United States should be even greater, since the proposed initial program is expected to demonstrate the practical and economically justified use of a nonexhaustible source of energy—the wind. The possibilities Nation-wide for saving of coal, oil, and gas are large.

Several factors indicate the desirability of the development of aerogenerators as a defense measure. Among these are:

(1) *No fuel requirement.*—This would remove some of the burden on the two greatest bottlenecks which exist during war, i. e., (a) labor required in obtaining fuel, and (b) transportation facilities to move fuel from source to powerplant.

(2) *Isolated units and dispersal.*—Aerogenerators would be located in relatively isolated locations, usually distant from concentrated urban or industrial centers. Since design limits dictate multiple moderate size units, such units would be dispersed on a system, rendering the system less vulnerable to damage by attack.

(3) *Multiple moderate-size units.*—Units are necessarily moderate in size (under 10,000 kw), but in aggregate could make major contributions to power systems.

(4) *Short construction schedules.*—Once experimental and design data for the prototype are determined, a standardized unit could be fabricated and erected in probably a shorter time than a comparable fuel electric unit.

(5) *Minimum material requirements.*—The equipment would be comparable to that required for a fuel electric plant except that fuel storage and handling facilities would be eliminated. The wind vanes and coupling reduction gearing would be more than offset by the elimination of boiler and furnace equipment and fuel and ash handling facilities. The support tower of structural metal lattice construction would be largely offset by elimination of boilerhouse, chimneys, etc., of fuel electric plants.

Copies of a pamphlet prepared by the Bureau of Reclamation on the subject to which this bill relates are enclosed for your information. You will find in this pamphlet an elaboration of the matters covered in this letter.

The Bureau of the Budget has advised that there is no objection to the transmission to your committee of this report.

Sincerely yours,

WILLIAM E. WARNE,
Assistant Secretary of the Interior.

UNITED STATES DEPARTMENT OF THE INTERIOR, BUREAU OF RECLAMATION—PROPOSED DEVELOPMENT OF ELECTRICAL POWER FROM THE WIND

INTRODUCTION

EXPERIMENTAL AND RESEARCH WORK

United States

The successful operation of a 1,250-kilowatt wind-driven generator (also called aerogenerator herein) in 1945 as a regular unit of the Central Vermont Public Service Corp. utility system gave great promise of the practicability of development of wind power on a relatively large commercial scale. This marked the first use of wind power on such a scale in the world. The wind-driven generator with a capacity of 1,250 kilowatts was located on a small mountain in Vermont called Grandpa's Knob and its use during the period of its operation was reported as part of the normal system operation by the utility in its annual report to the Federal Power Commission.

Great Britain

Considerable research and investigations are now under way or authorized in Great Britain to determine the possibilities of harnessing the winds of the coastal districts of the north and west of Great Britain on a commercial scale. These winds, which have a high annual energy content, present opportunities for feasible development of power which in the aggregate might equal or exceed the energy which can be obtained from the whole of the existing and potential water power resources of Great Britain.

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A news dispatch dated November 9, 1950, from London, states that experts of 10 European countries were meeting there to discuss the technical and economic aspects of wind power in generating electricity. They were scheduled to compare experiences in research and draft plans for exchanging information to avoid duplication in research. Representatives of British Commonwealth countries and of the Economic Cooperation Administration were also expected to be present.

Preliminary Design Work

For nearly eight years investigations by the Federal Power Commission, under the direction of Mr. Percy H. Thomas, were made in the United States and particular study was given to the development of designs for a wind-driven generator of substantial capacity. The results of these studies indicate that wind-driven generators of 5,000- to 7,500-kilowatt capacity or even more are practical. Such equipment constructed and erected at sites carefully selected so as to provide the maximum utilization of the prevailing wind velocities, if integrated into utility systems having other power supplies available on demand, appear well justified for further exploration.

APPLICATION

Fundamentally, an aerogenerator is a device for converting the energy content of the wind to useful electric energy. Due to the fact that wind velocity is variable, the use of an aerogenerator alone as a dependable isolated power source is not practical. In the Grandpa's Knob development in Vermont, the electric energy output was integrated with the system, consisting largely of hydroelectric plants of the Central Vermont Public Service Corp. Operation was such that when the wind velocity was moderate or high, output of the wind driven generator in commercial amounts of electrical energy was obtained and delivered into the power system. At these times the output of the hydrogenerators in the rest of the system was reduced and the water conserved in the reservoirs for later use. When the wind power was inadequate, water stored in the reservoirs was released and the output of the hydrogenerators was increased. This shift of loads was entirely automatic and presented no operating problem.

PRESENT DEVELOPMENT

Considerable valuable design and test experience data have been obtained to date. However, the final development of an economical and efficient aerogenerator of practical commercial size requires further research, special design and test. The following procedure is, therefore, considered essential in connection with the production of a full-size prototype of 7,500-kilowatt capacity. The proposed program is divided into two stages: (1) Investigations and research; and (2) construction of initial aerogenerator units. It is estimated that it will require 3 years to complete all work required in the two stages to put the initial unit into commercial operation.

INTEREST OF BUREAU OF RECLAMATION IN UTILIZATION OF WIND POWER

The Bureau of Reclamation's power systems located in the West are completely hydroelectric at the present time, and in the near future will probably remain so, with the exception of additions of necessary supplemental power for firming purposes. Such supplemental energy is now supplied from nonbureau fuel-electric plants. Development of financially and technically feasible aerogenerators for use in such systems is practicable and quite desirable because there is no fuel cost involved in its operation. It now appears entirely reasonable, once specific designs are proved, for substantial quantities of electric energy to be generated by such generators properly located and absorbed into a power system so as to utilize to the best advantage the energy of the wind. These wind-power plants would be used to furnish supplemental energy only, as required by the Bureau power systems, thereby greatly augmenting the firm energy available from hydro power plants only. Such supplemental source of energy, even though noncontinuous, is economically desirable because wind power is not a limited energy source and the cost of operation does not include fuel costs. The problem in almost all parts of the West is that there is an inadequate supply of water to meet the needs of the people. Therefore, supplemental supply of energy is a necessity and the most economical means of providing such supplemental energy to that produced by hydro plants should be adopted.

PROPRIETY OF FEDERAL PROGRAM FOR WIND-POWER DEVELOPMENT

For the 1,250-kilowatt Smith-Putnam wind turbine test installation at Grampa's Knob, Vt., the sponsors of the project ,the S. Morgan Smith Co., between 1939 and 1945 had spent over a million and a quarter dollars for the necessary research, development, and other work carried out. This probably covered almost all but not the entire cost of the project since several firms and technical experts cooperated in the project, and donated at no cost equipment, materials, or services to the project. Of the money spent on this project, perhaps a quarter of a million dollars was used in making meteorological studies in various parts of this country and the world, as well as on investigations of alternative wind-power sites in New England. The project was finally abandoned after the success of it had been technically demonstrated because it would have cost the chief sponsor, the S. Morgan Smith Co., several hundred thousand dollars more to complete tests, eliminate minor weaknesses of design and to pioneer sale of such wind turbines on a financially sound basis. Also at that time the immediate prospective market did not exist. The company, therefore, reluctantly abandoned the project for financial reasons and not for lack of demonstrated success. It placed its patents in the public domain.

Although there is great national and international interest in wind power as heretofore discussed, no private companies or public organizations in the United States other than the Federal Government are now in a position to continue actively in developing and constructing a prototype wind power plant of substantial capacity, even though such development as a supplemental power source is justified. The privage companies and organizations participating in the Grandpa's Knob project have already performed a monumental service to the Nation in demonstrating the commercial practicability of wind power, but as stated above, have been unable to proceed further with this. It therefore, devolves upon public agencies concerned to continue the development since it is in the public interest to do so. The Federal Government and the Bureau of Reclamation because of its particular and immediate need for electric energy to supplement its deficient hydro systems is peculiarly in the position to justify taking the lead in continuing and furthering the wind power development program proposed herein.

It is believed that the benefits to the particular project and area in which the equipment would be located would justify the cost. Not only will more firm energy be provided in power-short areas but such supplemental production is estimated to be more economical than supplies from other potential sources. Furthermore the estimated revenues will fully repay the costs and may well provide some surplus revenue. The benefits to the entire United States should be even greater, since the proposed initial program is expected to demonstrate the practical and economically justified use of a nonexhaustible source of energy—the wind. The possibilities Nation-wide for fuel saving of coal, oil, and gas, as a conservation measure, are large.

According to the paper, "Harnessing the Wind for Electric Power," presented by Percy H. Thomas at the United Nations' scientific conference on the conservation and utilization of resources in 1949, a substantial portion of the total energy of a power system can be expected to be economically obtained from wind energy. The following figures would apply for systems with hydro storage in areas where wind conditions are favorable. It is estimated that as much as 25 to 40 percent of the system energy may ultimately be produced from wind power on an economically justified power system.

POSSIBLE BUREAU SITES

Unquestionably in a number of areas in which the Bureau of Reclamation operates there are promising locations where the generation of power from wind could most advantageously be used to supplement the Bureau supply of hydroelectric energy. For example, preliminary examination shows that the Sherman Hill area in southeast Wyoming near Laramie is a water-short area where generation by wind power could make substantial increases in firm energy by integrating the operation of aerogenerators with the operation of the reservoirs and the Bureau's hydro-power systems. In this location Bureau transmission lines are available so that a short connection only is needed to integrate the power so generated with the existing power system.

PREVIOUS EXPERIENCE

For some years past, various experimental wind-driven generators have been designed, constructed, and tested in various parts of the world. The most recent, largest, and most successful was the earlier-mentioned Smith-Putnam wind turbine erected at Grandpa's Knob in Vermont.

This turbine generator consisted of a two-bladed 28.7 r. p. m. constant speed wind turbine, driving through gearing and hydraulic coupling, a synchronous alternating current generator. The turbine-generator assembly was mounted on a rotating housing or structure on top of a 110-foot fabricated steel tower.

This experimental unit developed an output of about 1,000 kilowatts at its rated speed with a wind velocity of approximately 30 miles per hour. It was operated successfully under test for about 1,100 hours and for a period of approximately 1 month was placed in regular commercial operation on a public-utility system. Operation was discontinued after a blade failure, due to a structural weakness, which was analyzed as a minor defect incidental to the design and capable of being corrected without radical change in design.

ECONOMICS OF AN AEROGENERATOR

The economic value of an aerogenerator lies entirely in its ability to produce electrical energy as a supplemental supply to a power system which has other electrical capacity available when the wind power is not available. Because of the intermittency and variation in velocity, it cannot be operated independently as a dependable source of power. It is, however, particularly valuable if its supply is coordinated with hydroelectric power supplies on systems on which water storage is available but the water supply is limited. On such systems, recourse to a supplemental supply of electric energy is necessary. However, the supplemental supply need not be continuously available since the water storage of the hydro system will automatically supply hydroelectric energy as needed; i. e., when wind power is deficient. Vice versa, the energy from an aerogenerator can always be used whenever available. The ability of aerogenerators to produce a fairly uniform annual amount of electric energy is of importance because there are no fuel costs, so that the only costs are fixed charges, and labor operating costs and maintenance costs. Since a properly designed aerogenerator has long life characteristics with relatively low maintenance costs, the fixed charges should compare very favorably with hydroelectric plants. On the other hand, with no fuel costs, the annual cost of operation is comparable to a hydroelectric plant and much less than a fuel elcetric plant.

A large amount of meteorological data indicates that there are numerous sites in various parts of the United States where the wind velocity and annual availability of wind power appear to be sufficient to justify construction of commercial size units. In order to be financially feasible, sufficient energy production (kilowatt-hours) must be produced per kilowatt of installed capacity to get the cost per kilowatt-hour down to, or less than the cost of a supply of energy from an alternative fuel electric plant source.

COST OF WIND POWER ENERGY

Preliminary study and tests, meteorological data, and tentative designs indicate that an annual output of 3,500 to 5,000 kilowatt-hours per kilowatt of installed capacity may reasonably be expected at a number of potentially desirable sites in the west. As a part of the research part of this project, determination of adequate meteorological data at the site selected will be a prerequisite to construction of any prototype aerogenerator. The following table shows the estimated cost per kilowatt-hour of energy produced by an aerogenerator. These costs are based upon various construction costs and upon various annual outputs in kilowatt-hours of installed capacity. The estimated cost per kilowatt-hour at the wind power site includes cost of operation and maintenance, replacements during the repayment period, and amortization of construction cost in 50 years with interest of 3 percent on the unpaid balance.

TABLE 1.—*Estimated cost of energy produced by an aerogenerator*

Capacity factor (percent)	Annual energy production, kilowatt-hours per kilowatt of capacity	Estimated cost of energy in mills per kilowatt-hour—Construction cost per kilowatt of capacity					
		$100	$150	$200	$250	$300	$350
60	5,256	1.90	2.47	3.04	3.61	4.19	4.76
55	4,818	2.08	2.70	3.32	3.94	4.57	5.19
50	4,380	2.28	2.97	3.65	4.34	5.02	5.71
45	3,942	2.54	3.30	4.06	4.82	5.58	6.34
40	3,504	2.85	3.71	4.57	5.42	6.28	7.13
35	3,066	3.26	4.24	5.22	6.20	7.18	8.15

From this table it will be seen that with a construction cost of $350 per kilowatt or less and an annual output of 4,400 kilowatt-hours per kilowatt, the cost per kilowatt-hour will be about 5.7 mills. With an annual output of 4,000 kilowatt-hours per kilowatt, and with a construction cost of $300 per kilowatt, the cost per kilowatt-hour is about 5.5 mills; at $200 per kilowatt, the energy cost is reduced to about 4 mills per kilowatt-hour; and at $150 per kilowatt, the cost per kilowatt-hour is 3.3 mills.

As an example for cost comparison, a study in an area where all available steam generation is being used to the limit to supplement hydro developments so that any alternative supply to aerogenerator will have to come from the construction of new steam plants, the cost of such energy will be 6 mills or more per kilowatt-hour with the fuel cost alone amounting to 2.5 to 3 mills or more per kilowatt-hour. While the construction cost of the prototype aerogenerator (the first full size unit produced), including cost of meteorological investigations of the sites, model wind tunnel tests, and initial designs, may exceed the cost of a like capacity fuel electric plant, the cost of fuel will be eliminated and the cost of operation, maintenance, and replacements should be considerably less. After the research, design, and tests of the initial unit are completed, succeeding aerogenerator units can certainly be constructed at a much lower cost, which will very probably be not more than, and possibly less than, a similar capacity fuel electric plant.

In connection with the economic consideration of this development, the probability of future increasing annual operation costs is greatly less than with a fuel plant since rising fuel costs are not a factor in the operating costs. In this respect, such a generating unit has the same advantage as a hydro unit. Furthermore, an aerogenerator plant can be economically adapted to automatic control, thereby eliminating a major operating cost, i. e., salaries of the operating personnel. Automatic operation would also make very practical the construction of multiple moderate sized wind power plants located at the most advantageous sites without regard to convenient living conditions for operating personnel.

DESIRABILITY OF DEVELOPMENT AS A DEFENSE MEASURE

Several factors indicate the desirability of the development of aerogenerators as a defense measure. Amont these are:

(1) *No fuel requirement.*—Thereby avoids further burden on the two greatest bottlenecks which exist during war, i. e., (a) labor required in obtaining fuel, and (b) transportation facilities to move fuel from source to power plant.

(2) *Isolated units.*—Aerogenerators would be located in relatively isolated locations, usually distant from concentrated urban or industrial centers.

(3) *Multiple moderate-size units.*—Units are necessarily moderate in size (under 10,000 kw.), but in aggregate could make major contributions to power systems.

(4) *Short construction schedules.*—Once experimental and design data for the prototype are determined, a standardized unit could be fabricated and erected in probably a shorter time than a comparable fuel electric unit.

(5) *Minimum material requirements.*—The equipment would be comparable to that required for a fuel electric plant except that fuel shortage and handling facilities would be eliminated. The wind vanes and coupling reduction gearing would be more than offset by the elimination of boiler and furnace equipment,

and fuel and ash handling facilities. The support tower of structural metal lattice construction would be largely offset by elimination of boiler house, chimneys, etc., of fuel electric plants.

(6) *Dispersal.*—Since design limits dictate multiple moderate size units, such units would be dispersed on a system, rendering less vulnerability to damage by attack.

PROCEDURE OF DEVELOPMENT

(1) *Investigations and research.*—During this stage efforts will be directed toward accomplishing the following work for which the estimated cost is $250,000.

(*a*) *Investigation.*—A number of sites in the western United States appear to be quite promising for location of the initial unit, and must be given preliminary investigation to determine the site location for the initial installation. After this site is selected, specific meteorological data will have to be obtained. This will require the establishment of a meteorological station or stations with necessary equipment and personnel. It is estimated that meteorological investigations of the initial site must be continued over a period of 6 months to a year.

(*b*) *Model design and tests.*—Simultaneous with part (a) and prior to completion of final full-scale designs, the aerodynamic characteristics of proposed designs must be determined by wind tunnel tests on models. This will predetermine operating characteristics, including efficiency and output, and will be a necessary prerequisite in determining final designs. Estimated time—Model construction and wind tunnel tests—12 months.

(*c*) *Preliminary prototype design and technical studies.*—Concurrently with (a) and (b) and based on the results of the model tests, preliminary design and technical studies will be initiated and cost estimates prepared. Such consultant services as are necessary will be engaged. During this part of the work the economic feasibility of the aerogenerator will be substantiated and decisions made with regard to the continuation of the work into the second stage. It is estimated that this part of the work will require 15 months.

(2) *Construction of initial aerogenerator.*—During the second stage, final designs and specifications will be completed, invitations for bids advertised, and contracts awarded for the manufacture of initial aerogenerator unit. The necessary construction work at the site will be performed and the aerogenerator erected, tested and put into commercial operation. It is estimated that this stage of the work will require about 21 months and will cost between $2,000,000 and $2,500,000 to complete. This estimate is subject to revision after conclusion of part (1) as the final design will depend largely upon the results of the technical investigations and model tests.

DEPARTMENT OF THE INTERIOR,
BUREAU OF RECLAMATION,
Washington, 25, D. C., January 15, 1952.

Hon. JOHN R. MURDOCK,
Chairman, Committee on Interior and Insular Affairs,
House of Representatives, Washington 25, D. C.

MY DEAR MR. MURDOCK: On May 28, 1951, you introduced H. R. 4286, a bill the enactment of which would materially aid the investigation and development of wind power as a source of electric energy. The work proposed to be undertaken pursuant to this bill may well open a vast new field of important electric power production in the United States. A great deal of interest has been evinced in such development not only in this counrty but in many other countries.

I need not repeat here the reasons for our support of and interest in this measure. These were fully set out in Assistant Secretary Warne's report of September 11, 1951, to your committee. I may point out, however, that the success of potential development in this field depends primarily upon coordination with other forms of power supply, especially hydroelectric supply where the water available is limited, and that an engineering organization such as that of the Bureau of Reclamation, experienced as it is in the construction of multipurpose water projects, is peculiarly well equipped to carry out this type of research and to apply the advantages of successful results to many of its existing and potential projects.

To the best of my knowledge, H. R. 4286 is noncontroversial. I hope that your committee will see fit to take early and favorable action on this measure.

Sincerely yours,

MICHAEL W. STRAUS, *Commissioner.*

FEDERAL POWER COMMISSION,
Washington 25, July 13, 1951.

Reference: H. R. 4286, Eighty-second Congress, first session.

Hon. JOHN R. MURDOCK,
Chairman, Committee on Public Lands,
United States House of Representatives, Washington 25, D. C.

DEAR MR. MURDOCK: This is in response to your request for a report within 10 days on the above bill: Authorizing investigation, research, and development work by the Secretary of the Interior and the construction and operation of facilities, including not more than one demonstration plant, to determine and demonstrate the economic feasibility of producing electric power and energy by means of a wind-driven generator operated in conjunction with an electric power system, and for other purposes. The Commission has had some experience in the study of aerogeneration during the past few years which may be of some assistance to you.

Section 311 of the Federal Power Act (49 Stat. 859; 16 U. S. C. 825j) in part provides that "the Commission is authorized and directed to conduct investigations regarding the generation, transmission, distribution, and sale of electric energy, however produced, throughout the United States and its possessions, * * * including the generation, transmission, distribution, and sale of electric energy by any agency, authority, or instrumentality of the United States, * * *." Pursuant to this congressional mandate one of the high-ranking engineers of the Commission undertook an exploration of the possibilities of tapping wind power as a means of generating energy upon a basis suitable for general use. After extended research and study of the problem in which the Commission fully concurred the enginer in question, Mr. Percy H. Thomas, brought his efforts to the point where it appeared that he had developed an idea possessed of substantial value and of sufficient novelty to warrant protecting it by patents. Accordingly applications were duly filed for patents and appropriate assignments made to the Federal Government of all rights therein upon the issuance of patents which occurred May 24, 1949, and June 13, 1950, and are numbered 2,470,797 and 2,511,023, respectively.

Since the Government bore the cost of such research and investigation and became assignee of the patents issued upon the design of the device for converting wind power into electric energy it is most fitting that an agency of the Government should undertake the construction of such device and as a result of such experimentation definitely establish the practical value of the idea.

The facilities for the generation of electric energy are hard pressed to keep ahead of the demands made for such service and at the same time have in reserve sufficient capacity to insure continuity of service in the event of breakdown of equipment or its temporary withdrawal to facilitate overhaul and maintenance. Accordingly any plan which tends to enhance service to customers is to be favored and since the aerogenerator converts wind power into electric energy and is in no way dependent upon stream flow or availability of fuel for steam generation its use is eminently justified.

In order to obtain the maximum benefits of the aerogenerator it should be coordinated with and used in a system which has for its primary source of energy either or both hydro and steam generation. During such time as the aerogenerator is producing electric energy water is not being discharged for hydro generation nor fuel consumed for steam generation with resultant conservation of natural resources in each instance.

The design of the aerogenerator represents several years of intensive study and research by a competent graduate electrical and mechanical engineer of many years of practical experience and clearly is a distinct contribution in that field of activity. The work was carried on in the offices of the Commission with the expectation it would prove to be a valuable contribution to the industry with resultant benefits to the public generally.

A more detailed recital of the various important aspects of the device are set forth in a volume entitled "The Wind Power Aerogenerator Twin-Wheel Type" prepared by our engineer, Mr. Thomas, and six copies thereof are transmitted herewith for the use of the committee with the hope that it will be favorably disposed to recommend the adoption of H. R. 4286 and thereby establish the practical value of the aerogenerator as an essential component in the system of an electric utility as such systems are presently constituted and operated.

The Commission recommends the adoption of H. R. 4286.

The limitation of time has precluded clearance of this report with the Bureau of the Budget.

Respectfully submitted.

MON C. WALLGREN, *Chairman.*

The CHAIRMAN. We have this morning Secretary Warne. I might say in advance that we have favorable reports on this bill from the Interior Department.

Secretary Warne will probably go into that a little more fully. We have a report from the Federal Power Commission.

We welcome you back, Mr. Secretary, after some absence.

STATEMENT OF WILLIAM E. WARNE, ASSISTANT SECRETARY OF THE INTERIOR

Secretary WARNE. It is a pleasure to be here before your committee, Mr. Chairman. I suggest you might wish to insert our report on the bill at this time, and to know that we sent with that report a little volume entitled "Proposed Development of Electric Power From Wind," which was prepared in April of this year, and of which I have brought copies for distribution among the committee this morning.

The CHAIRMAN. You are right, Mr. Secretary. The bill itself will precede, followed by the reports from the Department.

Secretary WARNE. It is a pleasure to testify in behalf of a bill which would advance the utilization of one of our valuable natural resources—wind power.

I suppose some may think it a little fantastic that we come here and seriously discuss harnessing the winds, but it is quite the reverse for the reason that windmills are as old a power mover as we have had in this country. It seems to me we ought to have been here long before. In truth, in other nations a great deal of work has been done in areas that are not nearly so favorably situated as we are with regard to constant, or nearly constant, wind movements.

It is time that our Nation, traditionally the leader in technical advancement, utilize more of the tremendous, inexhaustible energy contained in the winds which blow across our prairies and our mountains. The enactment of H. R. 4286 would be an appropriate first step. At a period when we must increase the strength of our economy and build up our power potential we cannot afford to permit to continue the waste of a source of energy potentially as great as wind power. From facts available to us now, it would appear that wind-driven electric generators constitute a practicable means for adding to the power resources of our Nation at moderate cost and with comparatively small use of critical materials. Privately and publicly owned utilities alike are presently engaged in the most rapid period of expansion in their histories. Electricity generated from wind power is a promising method of augmenting our national power supply. We should get on now with the final stages of experimentation with wind power so that the Nation can draw on this resource.

Large-scale generation of electric power by utilization of the energy in wind has progressed far beyond the dream stage. A wind-power installation, financed by private interests, has already been successfully tested in Vermont, at a place called Grandpa's Knob. As a matter of fact, there is a picture of that generator here, supplied by Mr. Thomas. I call your attention to it over here [indicating]. This is one that actually was operated for a time on the line of a power company in Vermont. This plant was for a time integrated with the system of the power utility in the area and so provided commercial power. Certain defects in its design developed—it was built by the S. Morgan

Smith Co., a manufacturer—and the organization which advanced the initial capital funds found itself unable to expend the additional amounts necessary to remedy those defects. The organization was not primarily interested in continued operation of the plant on a commercial basis but rather in the results of the experiment. I understand that the owner was completely satisfied with the practicability of wind-power generation as a result of this test, but in view of financial consideration it abandoned the project and placed its patents in the public domain. It, in effect, said, "Let someone else come forward now and carry this on another step."

It is logical that the Government of the United States take the next step in the investigation and experimentation in the generation of electric energy from wind power on a relatively large scale. Private interests have commendably broken the trail in the matter, but further advancements under private auspices do not appear likely, at least for many years. Meanwhile there is, as I have said, a growing need for developed power resources, and it is appropriate now, in my judgment, for the Government to enter the picture in an organized, orderly way.

This Government is already 3 years behind the Government of Great Britain in its research activities on wind-power generation. During the summer of 1950 it was my privilege to attend a meeting of the Fourth World Power Conference in London as the official delegate of the United States Government. The conference was attended by some 1,600 representatives of 54 nations for the purpose of discussing current developments and problems in the electric power field.

In a paper presented by two representatives of Great Britain at the conference, they noted that a committee on wind-power generation was established by the British Government in January 1948.

I have that paper here this morning. It is a very interesting paper. They describe the work that they are doing, and are planning to do there, which is about parallel with what we are proposing here to do.

The CHAIRMAN. Have you more than one copy? Can you submit that for the inspection of the committee?

Secretary WARNE. I would be happy to do that, and would like, if practicable, to get it back since it is my only copy of this paper.

The purposes of the British committee are similar to the purposes of H. R. 4286. British authorities, acting under the auspices of the committee, have already placed under contract at least two wind-driven generating plants.

What we do know now about wind power—and that is considerable—indicates that wind-driven electric generators are feasible, and to be feasible must be interconnected with electric power grid systems to which are also interconnected hydroelectric and/or fuel electric generating plants. In other words, we do not believe at this time that a wind power plant standing alone would be a feasible undertaking, or that one or two wind power plants standing together but not connected with another source would be feasible as central service stations. We believe that if they were tied into a system which had other types of generation that they would be feasible. They complement and supplement both fuel generators in that they provide a means of saving fuel, and hydro plants in that they provide a means of saving water and thereby increasing the general over-all output of the hydro plant.

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Mr. MORRIS. May I ask the Secretary one question on this particular point?

Mr. Secretary, this has been worrying me about the matter. We have had some hearings on it before. You mean while the wind-driven plant would be in operation the steam plant or hydroelectric plant would be resting during that time; is that the idea, in effect?

Secretary WARNE. That is correct. The wind flows like water, but not in a stream. If you had six power plants on a river, a single river, and were able to utilize the water that appeared in that river through those plants, when one plant was low they would all be low, and you would, in effect, multiply your power weakness in the plants. However, if you had six wind-driven plants at various locations you would not multiply your weaknesses because the wind is inconstant. It may blow more nearly constantly in some locations than at others. It is inconstant but it is not inconstant in the sense that it is quiet in all places over a wide area at one time. There is motion in the atmosphere at all times, and the generation from wind power would give a very smooth curve. You could fill the valleys of the curve with generation from water power which would enable you to generate more firm power out of the same amount of water in the river. It would give you a more stable output from your system. On the other hand, if it were steam plants to which you had the wind generators interconnected it would give you a fuel saving.

Now, there is a great deal of energy, almost an astronomical number of kilowatt-hours, available in the wind, if it feasibly can be captured and utilized. We believe that the techniques are known and have been demonstrated through the plant at Grandpaw's Knob, which developed a structural weakness, to be sure, but that weakness can be corrected, we know it can be corrected engineeringly now. We believe, especially in some of the western areas where water is a very important resource, and where winds are known to be more nearly constant than in some other places in the country, that this would be a very useful development.

Mr. MORRIS. Just one other point: Is it your contention that the operating expense of the wind-driven facility would be much less than either the steam or the hydroelectric operating expense?

Secretary WARNE. The operating expense would be less than either?

Mr. MORRIS. Yes.

Secretary WARNE. Yes.

Mr. MORRIS. That would be in the field both in the saving of fuel, which, of course, naturally it would be because the wind is provided by nature, but would it also be in the field of labor? Would there be less labor?

Secretary WARNE. We think several of these plants could be operated in tandem by a single operator, almost automatically.

Mr. MORRIS. That is all. Thank you.

Mr. CRAWFORD. Mr. Secretary and Mr. Chairman, I remember the day I had the honor of being a range rider taking care of the windmills. Can all this be summarized by simply saying these would be feasible as supplementary power?

Secretary WARNE. They would be feasible as supplements to a power system.

Mr. CRAWFORD. That is right. In no way could you rely on the strictly wind-driven generator for a power system?

Secretary WARNE. As we gain additional knowledge of where these winds occur, at what elevations above the ground, and at what locations particularly, it is conceivable to me that we could have a system which could rely on wind-driven generators alone, but on an individual generator you are quite right, there could not be reliance. At the time when you would be becalmed you would not have any electric energy, and there are such periods of absence of wind everywhere.

Mr. CRAWFORD. We have never designed a system where we could depend entirely and absolutely on steam and hydroelectric power?

Secretary WARNE. You could depend absolutely on steam.

Mr. CRAWFORD. Without auxiliaries?

Secretary WARNE. You have to have stand-by plants, of course.

Mr. CRAWFORD. That is it exactly, you have to have a stand-by plant on everything that produces power.

Secretary WARNE. That is true. There isn't any such thing as setting up a single machine and operating it at full capacity at all times with reliability, and in this particular field constant service is something that we have come to believe is essential. We just cannot tolerate outages lasting for hours and days, as they do in some parts of the world. Such service is not desirable and it can be avoided. Our consumers demand good service, so there must be auxiliary generators.

The CHAIRMAN. If I may add a comment right at that point, I understand that there is one Municipal power-producing plant that pumps water in off periods up to a considerable elevation, and then uses that power from falling water to help supply power in the peak period. Something of that sort might be worked out with regard to the use of water, if you do not have to have a constant supply in a large reservoir, and let wind power do the work.

Secretary WARNE. There are places in the world where geographically the ground is situated so that that kind of operation appears to be feasible. I think the corps of engineers designed the redevelopment of the Niagara project to incorporate a reservoir to which at times of plentiful flow and low power demand some water will be pumped to be used in peak periods of energy demand. We have given consideration to that arrangement in connection with the possibility of developing a third power plant in Grand Coulee Dam, which is favorably located for it. There are all kinds of opportunities to stabilize the power output from the hydro plants. That is one of them. The incorporation of a wind-driven generator, or several of them, in such a system would be useful, too, for the same purpose.

The wind, of course, is an inconstant source of energy, providing little or none on calm days and a great deal under favorable wind conditions. In these circumstances, it is necessary that the output of wind-driven generators be fed into a grid system, which can make use of intermittent energy.

Efficient use of large wind-driven generators requires integration I think I pointed this out already. When the wind is blowing and power from wind plants is available, hydroelectric plants on the same grid could reduce their output in proportion. Water so conserved would be retained in storage for power generation at other times when the output of the wind-driven station is reduced by calm weather conditions. The interconnected power system could thus make good use of wind power when it is available, whereas, the output of a wind

generator, by itself, would be of little commercial value because of its intermittent character.

The Department of the Interior is in the logical position to discharge effectively the Federal Government's responsibility for research in this field. Our Department, as you know, is charged by law with the duty of marketing all federally generated power outside of the TVA area. In carrying out this responsibility the Department has constructed transmission grids in several parts of the country, interconnecting public and private generation facilities with major load centers. The Department's largest grids are in the Pacific Northwest, the Pacific Southwest, the Missouri River Basin, and the southwestern area. In these areas the Federal generating facilities are entirely hydroelectric. The use of wind-generated power in such systems is, as I have indicated, the most effective method of utilizing wind power.

Water in the West is, as you gentlemen well know, a scarce commodity. Conservation of water through introduction of wind-driven generation into hydroelectric power systems is therefore particularly attractive in furthering western development.

Of equal importance is the possibility of firming the power output of hydroelectric systems by the use of wind power during periods of low stream flow. This possibility applies not only to the West, but to all other parts of the country which are served by hydroelectric power systems.

Wind-driven power generation is attractive also on the basis of conservation of materials, manpower, and natural resources, in addition to water. The operation of a wind-driven generating plant would, of course, involve no fuel transportation problem. There would be no demand on transportation facilities and associated manpower that are characteristics of fuel electric plants. Wind energy is inexhaustible. Its use might save oil that otherwise would be used as fuel in steam plants. Petroleum conservation has long been one of our basic national policies, and the saving of oil is particularly urgent in times of national emergency such as the present.

The other aspects of the proposal which are related to our current defense program deserve attention here. One is the security provided by isolation and dispersal of wind-driven electric generators. It is believed that the generators, if demonstrated as practicable by the experimentation contemplated in H. R. 4286, would be built in relatively isolated locations, probably distant from concentrated urban or industrial centers. What we presently know about wind generators would indicate that best utilization can be realized from construction of a number of moderately sized units rather than a few large sized ones. Both the isolation and the dispersal are in accord with suggestions which have been advanced by those responsible for civil defense for obtaining security of electric power facilities from sabotage or enemy attack.

The other defense related aspect is the comparative brief construction period which wind power plants are likely to require. As I have said earlier, the Nation needs new power sources as fast, or maybe faster, than they can be provided. When experimental and design data for the prototype envisaged by H. R. 4286 have been proven, it should be possible to fabricate and erect standardized units in a relatively short time as compared to fuel electric units or hydroelectric plants.

The first step in the experimentation program which would be authorized by H. R. 4286 probably would be a thorough study of all relevant data on design, construction, and operation of wind-driven generators. A considerable body of such data is in existence, both in this country and abroad. Mr. Percy Thomas, who is here this morning, and who, for many years, was with the Federal Power Commission, and became their authority on the possibility of wind generation, and others, notably P. C. Putnam, have conducted a great deal of research in the field on their own initiative. There is, of course, a full file of data available on the Grandpa's Knob installation in Vermont, which I mentioned earlier. I understand also that large wind-driven generators have been designed in France, Germany, and Russia, as well as in Great Britain.

The next step would be a detailed wind-velocity survey to determine the most promining sites for the erection of a pilot plant. Long-time records of wind velocity are maintained by the Weather Bureau of the Department of Commerce and these, of course, would be thoroughly examined. It would probably also be desirable to establish supplemental wind-measuring stations in advance of construction on the pilot plant.

I mention that for the reason that we have every reason to believe in certain places at elevations a few hundred feet above the ground the wind velocities are greater and more nearly constant than at the surface.

Consideration of logical sites for the installation of the pilot plant supports assignment to the Department of the Interior of responsibility for carrying out the wind power research program. It appears that the area in continental United States where wind velocities are high and are sustained over the longest periods is in the Great Plains region and adjoining the foothills areas where, as I have noted, the Interior Department has constructed and is continuing to construct extensive power grid systems interconnecting public and private hydroelectric and fuel power plants. It is likely that the pilot plant could be located on or very near to one of those grid systems, obviating the necessity of substantial transmission line construction to take the power from the pilot plant to an existing grid system.

Enough is known from experience in the Grandpa's Knob installation and from other sources of information about construction of wind-driven generation plants to indicate the desirability of planning for a pilot plant with an installed capacity in the neighborhood of 7,500 kilowatts. The cost of research and of building the pilot plant is presently estimated at $2,250,000 to $2,750,000. Such a plant would be small enough to avoid excessive experimental construction costs, and well within feasibility standards now established, and yet large enough to provide a significant contribution to power resources in the area where it is constructed at the end of the experimental period. Subsequent to the experimental period, additional units should be available to both private and public systems at a cost comparable to other types of generating equipment. That is our present guess.

H. R. 4286 wisely provides for the allocation of the cost of a demonstration plant to the cost of the Federal project of which the demonstration plant is made a part, exclusive of whatever costs may be assignable to investigation, research, and development work. In other words, when the plant has completed its service in the experi-

mental field it would be covered in as a part of the cost of the Federal project to which it was attached and would repay its cost, or that part of its cost which would be so allocated to power, and it would repay that part as the remainder of the project to which it would be attached would be repaid. Through this provision a substantial part, possibly the major part, of the Federal cost for the plant would be returned to the Federal Treasury, with interest.

In my judgment, the Nation needs further experimentation in wind-power generation now looking toward the expansion of its power resources and improvement in the output of its present power resources, all at little cost in money, material, and manpower. Despite our wealth of water and fuel resources, we cannot afford to let other nations out do us in wind-power development. I urge the enactment of H. R. 4286.

The CHAIRMAN. We thank you for your statement, Mr. Secretary.

Perhaps there are some questions that the committee would like to ask. Have you anything, Mr. Crawford?

Mr. CRAWFORD. I would like to ask probably two or three questions.

Mr. Secretary, will you give us, as briefly as you like, a rough idea of what you mean by a pilot plant of this kind?

Secretary WARNE. A pilot plant?

Mr. CRAWFORD. Yes, for this particular undertaking.

Secretary WARNE. At present we are thinking about a plant with the capacity of 7,500 kilowatts, which would have the regular standard generation equipment in it, and which would embody the design data gathered from Grandpa's Knob, and new designs that our engineers, Mr. Thomas, and others, have worked out. It would be a hand-built plant. In other words, it would have to be designed piece by piece and built piece by piece. The standards for it have not as yet been made, and that is why it would cost more. Then after it got into operation I think it is not inconceivable that we would find modifications which should be made, and which would be made, and tried out on this unit before other units would be proposed. That would cost something, too. In other words, a prototype would be a custom-built plant and it would be operated for a period of time to determine its economics and to test its designs and, if possible, to improve its designs, before we would say the experiment was completed.

Mr. CRAWFORD. Do you have in mind locating it at some point where it could be integrated?

Secretary WARNE. Yes, sir. We feel confident that the plant would remain in continuous operation after its experimental period, and, therefore, we would locate it at a place where it could serve continuously.

Mr. CRAWFORD. So far as you have been able to dig through this, is there considerable equipment on the market which you could place in this, or, as you say, would you have, perhaps, to make it a custom-built plant all the way through?

Secretary WARNE. The kind of equipment that would be available, which is already designed and approved, all of the electrical equipment. It is the part of the plant that would collect and transmit the energy of the wind which would have to be custom built, but the generator and all the electrical equipment would be standard. There is nothing experimental about that.

Mr. CRAWFORD. That is what I want to bring out. We have these little radio generators across the country, and I suppose you have drawn some experience from them.

Secretary WARNE. Well, they certainly are in the same field as the windmill used for a pump. They demonstrate there is energy in the wind, and it can be used, and is used very widely, as a matter of fact. They have the fault that all unconnected wind generators have, and that is that they are intermittent.

The CHAIRMAN. Mr. Morris.

Mr. MORRIS. I just want to ask one question: Has there been determined, taking into consideration the capital outlay and operating expenses, as to whether or not wind-driven generation would be cheaper or much more costly than hydroelectric or steam?

Secretary WARNE. Well, it is our judgment—drawing conclusions now from the studies that we have made—that we can introduce wind power as economically into a hydroelectric and steam system. In other words, we think that a wind-power plant can be designed and built that will prove itself and that thereafter other wind-power plants like it can be designed and built which will be competitive with both steam and hydro power.

Mr. MORRIS. The question I want to point out is this: It can be used only as a supplement. It is not constant because the winds are not constant. If it is possible it is not probable right now. But the question is, for the same amount of electricity over a period of time, taking into consideration the original capital and operating expenses, be more cheaply produced, or would it be more costly to produce by the wind-driven facility?

Secretary WARNE. Our present belief is that the power produced from the wind plant is cheaper than from either of the other sources. Now, you may have to gain a part of that economic advantage through placing a value on the water you save in the hydro system, but we think that the economics are in favor of integration of these wind plants on a hydro system.

Mr. MORRIS. That is all.

The CHAIRMAN. Mr. D'Ewart.

Mr. D'EWART. I might say, in answer to the question of the gentleman from Oklahoma, that the wind plant we have in Montana has always proven more costly than the REA distribution of power. I suppose, in part, it is because the cost of batteries is high. When you have a wind plant you have to have a very large storage battery in order to firm up the power when the wind is not blowing. I notice there is no storage plant at all contained in the bill.

Secretary WARNE. Mr. D'Ewart, we have not in mind here an attempt to provide steady power from the wind plant. What we hope to be able to do is to demonstrate that the wind plant is most useful when it is integrated with another power supply, as a means of providing energy when energy is available, and of saving on fuel and water during that period. I am fairly certain that a single one of these plants alone would have exactly the same disadvantage that you point out for the small ones which have been operated in the plains area already. They are not constant, and the business of providing carry-over storage batteries, or anything of that sort, runs their cost out of proportion to the other sources.

Mr. D'EWART. They generally run on 32 volts rather than 110, which makes it necessary to build special equipment that is a little more expensive than the 110-volt equipment.

Mr. MORRIS. That is the reason I asked the question. If this is a feasible thing then naturally that is a big element to consider, that is, whether or not it would be more costly.

Mr. D'EWART. The cost of equipment for wind plants in my State is more expensive, because they are on 32 volts rather than 110.

Secretary WARNE. That would not be true in the case of such a plant as we are proposing here. It would not be a small plant, but it would be a large plant, carefully located, and which would operate standard equipment and would bring out the power at whatever voltage is necessary to integrate into the system. So we overcome the disadvantages of the small, isolated windmill, or wind-driven power plant, in that regard. We think and hope that we will, by building a large unit, and integrating it into a system, overcome other disadvantages, too. That is essential, we think, to cut across the economic barrier on this thing.

Mr. D'EWART. I might further say for the benefit of Mr. Morris, we have these plants on the large stock ranges, but generally they supplement them with the Diesel plants. That makes very good firm power, a wind and Diesel plant, for an isolated plant where you cannot get REA service. It is not as satisfactory as REA service, but it does give a good service for those areas.

Secretary WARNE. By hooking a windmill to a Diesel plant you are doing exactly, on a very small scale, what we propose to do here, hooking a big wind generator on to a system that has another power source that can be used when the wind power is not available in quantity.

Mr. CRAWFORD. As I understand your point on this, you are not thinking in terms of building, we will say, a wind plant to run itself, but you are simply proposing to do something which will supplement something else in existence.

Secretary WARNE. That is right.

Mr. CRAWFORD. And nobody is going to be dependent upon this wind-driven proposition.

Secretary WARNE. No, sir.

Mr. CRAWFORD. Your main source of power will be your steam or hydroelectric and your wind operation will simply supplement that.

Secretary WARNE. That is right.

Mr. CRAWFORD. Then you get away from this Diesel or supplementary power to fit into the windmill proposition.

Secretary WARNE. That is right. It is conceivable that in time there will be enough wind generators in the country so some system will have its basic power supply from wind generators, but at this time, and for the purpose of this experiment, we are talking about utilizing the wind to supplement other power sources.

The CHAIRMAN. Mr. Aspinall, have you any questions?

Mr. ASPINALL. I have one question, and that has to do with the proposed cost of the installation, and also the authorization, Mr. Secretary.

In section 7 of the bill you ask for definite authorization, which I expect to be unlikely as far as this committee is concerned, but in your remarks, and also in the pamphlet which we have before us from the Department of the Interior, you suggest the cost will be some place between $2½ million and $2¾ million.

Will you tell the committee just how you arrived at the figures and whether that is to be the ultimate cost of this power plant? Is that the initial cost or are you, in fact, asking for more funds, for more authorizations?

Secretary WARNE. That was the cost estimate made a year or so ago, and it was arrived at by estimates of the amount of engineering research that would have to be put into it before we would be prepared to go forward with construction. We estimate that at $250,000. Then we estimate that the plant itself would cost between $2,250,000 and $2,500,000. Now, that estimate may be up a little at the present time, a percentage over the estimate of 18 months ago, but we think that is a fairly good estimate for the first one. We are not able to say as yet what an estimate of cost for later units might be, and I think we would not be in the position to say until after the first one has been built and operated.

Mr. ASPINALL. What is the relationship between the plant that was constructed at Grandpa's Knob in Vermont and the proposed program, relative to figuring the cost of the installation? In other words, these figures seem to be pretty closely related to me as I read the pamphlet and listened to your remarks. A quarter of a million dollars was spent at Grandpa's Knob for aerial surveys before the installation began, and then the installation cost about $1,250,000 or $1,500,000, which would be just about half of what you propose. I am just a little bit undecided as to how much you depend on what took place on Grandpa's Knob through private enterprise and proved to be not successful.

Secretary WARNE. Of course, the Grandpa's Knob experience figures very heavily in any calculation at this time in this field, but Grandpa's Knob certainly was not a failure, it did operate, and it operated on a commercial basis. They had a structural failure. As I remember, it was in the mill itself.

Mr. ASPINALL. In the blades, according to the report.

Secretary WARNE. Obviously that introduced a question of the redesign of the blades, but the owners chose to stop at that point, and very likely for good and sufficient reasons. We think we can start at that point and finish this job. I think S. Morgan Smith Co., and a lot of others who have studied this thing, will agree with us on that. I would like to have you ask some of these questions of Mr. Thomas who has really made many years' study of this project.

Mr. ASPINALL. Did Mr. Thomas have anything to do with the Grandpa's Knob installation?

Secretary WARNE. I am not certain of that. Perhaps as an adviser. He at that time was in the Federal Power Commission. He followed it very closely, and he has got a couple of prototypes and models here that I think he would like to show to you.

MR. ASPINALL. One other question: Have any studies been made as to whether or not the proposed locations of these plants might not be in the same vicinity as where our best hydroelectric plants are located at the present time? In other words, you might be firming up power for particular areas but you would not take care of the areas which are now short of power because of lack of natural resources.

Secretary WARNE. I think it can be stated as a fact that there isn't any place that lacks a wind resource. There are some that are more favorably situated than others, and we are not sure, of course,

at this time that we are able to identify all of those. The reason for going into an area where we have a hydro plant presently is, because we think that the wind generator reaches its efficient point only when it can be interconnected with a system.

Mr. Aspinall. Isn't this true, though, that the places you propose for experimentation might be called the windiest places that we have within our continental borders?

Secretary Warne. Well, I suppose Mount Washington, up near Grandpa's Knob, has at least the reputation of being about as windy as any place in the country, but we know that all along the Rocky Mountain front, and we know in any other area where there are differences of elevation on the ground that there are wind currents that have certain characteristics more or less favorable.

Mr. Aspinall. Of course I am familiar with the places you mentioned and, to me, they are the extreme and it seems to me to do an experimental job of this kind you should not go to the extremes either way, you should take what might be called a general situation.

That is all, Mr. Chairman.

The Chairman. The Secretary's comment that some of these questions should be directed to the engineer is a very pertinent one.

I might say that our lady Representative has the last word, and properly so.

Mrs. Bosone. Yes, Mr. Chairman, I shall wait.

The Chairman. Mr. Saylor.

Mr. Saylor. Could you tell us what the construction cost per kilowatt was in the Columbia Basin?

Secretary Warne. I could give that figure to you. It is about $150 per kilowatt. At the Grand Coulee Dam it was pretty low, lower than any place that we have in this country.

I could, if you like, give you a list of the dams and the approximate cost per kilowatt of capacity. My recollecion is it runs somewhere around $100 to $150 in the plant built in 1935 or 1936. You can't build a power plant for that today anywhere.

Mr. Saylor. Do you have any idea as to what the construction cost per kilowatt was in TVA?

Secretary Warne. I think that is available to me. I can supply it to you.

Mr. Saylor. I would also like to have the construction costs for a steam plant operating on either coal or oil.

Secretary Warne. All right, we can get that.

(The information requested is as follows:)

Department of the Interior,
Office of the Secretary,
Washington 25, D. C., September 21, 1951.

Hon. John R. Murdock,
Chairman, Interior and Insular Affairs Committee,
United States House of Representatives, Washington 25, D. C.

My Dear Mr. Murdock: In the hearings held by your Committee on September 19 with regard to H. R. 4286 (a bill authorizing investigation, research, and development work by the Secretary of the Interior to determine and demonstrate the economic feasibility of producing electric power and energy by means of a wind-driven generator, etc.), Representative Saylor requested certain cost data which I promised to furnish to the committee promptly. I am pleased to submit the following data:

Preliminary cost data now at hand indicate that the cost allocated to commercial power production at Grand Coulee will be approximately $100 per kilowatt; at Hoover power plant the cost so allocated is approximately the same. These

unit costs are exceptionally low because of the following two reasons: (1) Both installations are extremely large and were very economical to construct; (2) the major costs were incurred when the indices of construction cost were one-third to one-half of what they are today. On today's cost basis reproduction of the plants would cost from $250 to $300 per kilowatt.

The costs of commercial power facilities of other hydroelectric installations of the Bureau of Reclamation per kilowatt of capacity, translated to today's cost, are considerably higher. In general, they vary from $350 to $500, up to as much as $600 per kilowatt. Such installations have been well justified, however, because first costs of such hydro plants are the chief costs as there are no continuing fuel costs.

Today's construction costs per kilowatt for steam electric plants range from approximately $140 to $225 per kilowatt and up. The low cost per kilowatt is for very large capacity high economy plants, whereas the higher costs are for small plants with 5,000 to 10,000 kilowatt units. These small plants compare generally with the size of aerogenerators now under consideration.

It should be noted that contrary to the cases of dyhro or aerogenerator plants, the construction cost charges (fixed charges) are usually equaled or exceeded by the annual fuel charges. This is why the aerogenerator or hydrogenerator plant is at great advantage.

Mr. Saylor desired these costs to compare with the estimated construction cost of the proposed aerogenerator. It should be recognized that the present estimated aerogenerator prototype construction cost must of necessity be much greater than the costs of succeeding units, since with a proven design, the experimental and research costs will be eliminated. Also, as is now anticipated, once a sound design is proven and tested, commercial units would be of a semistandard design which, with repetitive manufacture, would bring the cost down materially. For these reasons we would expect the cost per unit to drop to two-thirds or one-half of the prototype cost.

It is trusted that the above information is that desired by the committee.

Sincerely yours,

WILLIAM E. WARNE,
Assistant Secretary of the Interior.

Mr. SAYLOR. Because it is very evident here, assuming you can construct a plant which will produce 7,500 kilowatts for $2,500,000, the construction cost is $333 per kilowatt.

Secretary WARNE. Certainly the costs are going to be high in the first one, Mr. Saylor, there isn't any doubt about that, when we are only building one of these plants. If we cannot prove anything by building one of them then I suppose it would be wise not to build them at all. We believe, however, we can build one of them and prove something by it.

Mr. SAYLOR. Has the Bureau at any time thought of contacting the people who put in the installation at Grandpa's Knob in Vermont? Has it thought about the finances that would be involved in taking over and operating that plant that is already installed?

Secretary WARNE. That would be a matter that could be considered here, but we are in contact with the S. Morgan Smith Co., for example.

Mr. SAYLOR. That is all.

The CHAIRMAN. Mr. Yorty.

Mr. YORTY. No questions.

The CHAIRMAN. Mr. Harrison.

Mr. HARRISON. No questions.

Mr. D'EWART. Can I ask another question in connection with what Mr. Saylor said?

The CHAIRMAN. Mr. D'Ewart.

Mr. D'EWART. Why can't we get the information that is required in this report, as Mr. Saylor indicated, at Grandpa's Knob, or from France, Germany, or Great Britain? Why can't we write those places and get all the information we need and get it without spending 5 million dollars?

Secretary WARNE. That is exactly what we propose to do. If the committee does it you will be spending just about the same amount for research as we propose to spend in this bill.

Mr. D'EWART. Do you think it would cost from 2 to 5 million dollars to send a couple of engineers to Holland, or Germany, to collect the data that they have already available?

Secretary WARNE. It is going to cost $250,000 for research. This is the amount for research. We would have to gather this information together and to make the design. Now, regardless of who does that, or how it is done, it costs about the same amount. Now, when you get the information together, depending upon how good the information itself is, we may have been able to shave the estimate on costs, and there may be fewer changes to be made after the first plant is built than we now estimate. What we say the cost of the plant will be is strictly an estimate at this time. It is based on really an absence of the information that you indicate is available, and which we hope to profit by.

Mr. D'EWART. You say in your report, "There is, of course, a full file of data available on the Grandpa's Knob installation in Vermont, which I mentioned earlier. I understand also that large wind-driven generators have been designed in France, Germany, and Russia, as well as in Great Britain."

I am just taking it from your report that this experimental work has already been done in other countries, in addition to Grandpa's Knob, and it is only a question of accumulating that data to get the very research material that we need in this country. It seems to me doing that would save quite a bit, perhaps $5,000,000.

My question is, why not do it that way instead of building one here?

Secretary WARNE. Well, it is still research until you get one built and it is operating, in my judgment.

The CHAIRMAN. Mr. McMullen.

Mr. MCMULLEN. No questions.

The CHAIRMAN. Mr. Aandahl.

Mr. AANDAHL. No questions.

The CHAIRMAN. Mrs. Bosone, have you any questions?

Mrs. BOSONE. No.

The CHAIRMAN. Mr. Secretary, I have a whole bunch of questions here, but you have answered a good many of them, and other questions will be passed on to the engineer.

Thank you very kindly.

Secretary WARNE. It has been a pleasure to be here, Mr. Chairman.

The CHAIRMAN. Mr. Percy H. Thomas is the engineer who has been asked to come this morning to go into the technical phases of it. As indicated in the beginning, we have favorable reports from the Federal Power Commission, as well as the Department of the Interior, and I will ask Mr. Wahrenbrock to introduce Mr. Thomas.

STATEMENT OF HOWARD E. WAHRENBROCK, ASSISTANT GENERAL COUNSEL, FEDERAL POWER COMMISSION

Mr. WAHRENBROCK. Mr. Chairman and gentlemen of the committee: I am Howard E. Wahrenbrock, assistant general counsel at the Federal Power Commission.

In response to your kind invitation that the Federal Power Commission be represented by an observer, they asked me to come here.

I am happy to introduce Mr. Thomas. In a legal capacity I have been associated, in such need as he had for legal advice, with Mr. Thomas from the beginning of the research which he did for the Federal Power Commission since approximately 1940 or 1941, and have been, as a personal matter, very much interested in his research. That research was carried on pursuant to authorization in the Federal Power Act for such investigation.

The Commission has caused to be published three studies which Mr. Thomas made. The first one was in 1945, I believe March of 1945, and it was called "Electric Power From the Wind." The second was in March of 1946, and we transmitted a copy of that study along with our favorable report to you. It is entitled "The Wind Power Aerogenerator-Twin-Wheel Type." Then in 1949 the third one was published. It is entitled "Aerodynamics of the Wind Turbine."

The Commission in its annual report for the fiscal year ending June 30, 1946, reported to Congress, briefly, on pages 90 and 91 of its annual report, concerning the studies which were then going forward. I might just quote the one sentence, "It has been estimated that at least 20 percent of the energy of a large network can advantageously be attained from the wind."

Mr. Thomas' ideas reached the point where the Commission participated in obtaining patents for them, and there have been issued patents for some of his inventions, and those are now in the public domain. Mr. Thomas is a respected engineer, beloved by all of his associates. The Commission, by its favorable report to you, is in effect sponsoring him as a technical witness before the committee.

The CHAIRMAN. Thank you, Mr. Wahrenbrock.

Now, Mr. Thomas, may we hear from you. You have not only been introduced, but you come as a graduate of one of the great engineering institutions of the country. When I learned that you were an M. I. T. man, that was the entrance to my favorable consideration first off.

Just be seated, if you will, and proceed with your testimony in your own way, Mr. Thomas.

STATEMENT OF PERCY H. THOMAS, CONSULTING ENGINEER, MONTCLAIR, N. J.

Mr. THOMAS. Mr. Chairman and gentlemen of the committee, to save time, and with your permission, I will read a statement that I have got here on the historical development of wind power. It is brief, and I could present it, and then if there are any questions that you choose to ask, I will do my best to answer them.

The CHAIRMAN. Go right ahead.

Mr. THOMAS. Utilization of the wind for power purposes has always been a goal to forward-looking engineers. In spite of the famous wind mills of Holland, and the 10,000 mills once serving England, these engineers have, until now, always been baffled by their failure to devise a machine efficient enough to extract power from the wind economically in comparison with power from steam or electricity, or to find means to overcome its intermittency. After the failure to advance these European wind-power undertakings, the activities of engineers decreased except for spasmodic attempts, until a United States engineer, Palmer Cosslet Putnam, broke down the impasse by

adopting from the airplane propeller the only known mechanical principle capable of producing power from the wind in competition with steam power—namely, the so-called intermittent impact principle.

Mr. Putnam persuaded the S. Morgan Smith Co., an engineering concern manufacturing large hydraulic and other machinery, to finance his new wind turbine. They are supposed to have been motivated by the expectation of future business in building the new turbines.

In 1941 a 1,000-1,250-kilowatt unit of the new type was installed on a mountain in Vermont known as Grandpa's Knob. In comparison with previous wind mills, this was a giant installation, having a wind wheel 175 feet in diameter, mounted on a tower 110 feet high. This is a picture of it here [indicating].

When completed this turbine actually generated the amount of power for which it was designed, and operated without difficulty, delivering its power into the lines of the Central Vermont Public Service Corp. in accordance with the variations of the energy in the wind from time to time.

The S. Morgan Smith Co. and Mr. Putnam, working in wartime, and without priorities, suffered long delays in completing the installation, but finally the long series of planned tests was completed and the unit was turned over to the utility for normal operation. All went well for about 3 weeks, when a long-suspected structural weakness developed, and one of the wings flew off down the mountain side, during the night, with a relatively low wind velocity. This accident, due to "metal fatigue," presented a dilemma, for the redesign and repair of this element was expected to require over $100,000. The S. Morgan Smith Co., having obtained all their test data, and having already spent a million and a quarter dollars, refused to advance more, and the installation was dismantled.

As the net result of this notable project, it was demonstrated that power may be taken from the wind in considerable quantities, and can be favorably absorbed in a normal utility system having steam and hydro generating units. The principal limitations appearing were the doubt as to the economic value of the power from this particular installation, and the small capacity of the unit, when pitted against efficient steam power in bulk.

It is interesting to note that, in accordance with its duty under the Federal power law, the Central Vermont Public Service Co. reported the Smith-Putnam wind turbine to the Federal Power Commission as one of its operating units. At the Commission this was considered notice that wind power might well become available for utility supply, and under its statutory mandate, authorizing the Commission to study the production of electric power, however produced, for the purpose of making recommendations to the Congress, a research project was started in the office of the chief engineer to study the potentialities of wind energy for electric power generation. Some 8 years was required the project not being completed until 1949. It was found necessary in this work to go far afield, for little adequate material was found, bearing on the design of wind turbines.

I would like to have you notice that sentence. It was found necessary in this work to go far afield, for little adequate material was found bearing on the design of wind turbines.

This study of the aerodynamics showed that very much higher efficiencies were obtainable than were reached in the Smith-Putnam

turbine, thus opening up the possibility of obtaining power from the wind on a basis more economical than from high-class steam plants, for bulk supply. Realizing the importance in utility work of units of much larger capacity than 1,000 kilowatts, a study design, showing all essential details, was made at the Commission with a capacity to generate 7,500 kilowatts, large enough to be attractive. This increase in capacity was obtained by utilizing two wind wheels in place of one; by increasing the diameter from 175 feet to 200 feet; by using three blades per wheel in place of two; by doubling the speed, and by utilizing more efficient blade sections.

The difficulty from the instability of the wind supply to a particular turbine was covered by confining the consideration of the use of the wind to our existing large electric-utility systems supplied with hydro storage, and at least for the first undertakings limiting the amount of wind energy to be utilized in any particular network to somewhat less than half of the system total. In this case, the hydro-storage reservoirs and the other reserves provide for firming the hydrogeneration during dry years, but they are suitable also to firm wind energy, the storage thus serving double duty. This would seem to limit the capability of the storage for its hydro duties but since the deficiencies of the wind are limited to a few days while the water lack in the rivers is for months or even for a year, the use of the storage for firming the wind handicaps it very little in its original work.

The essential data and recommendations in the Commission research were presented by the Commission in three comprehensive monographs, these completing the project. Most of the research was carried out by the speaker for the chief engineer of the Commission. Soon after this duty was completed he was retired from the Government service under the statutory age limitations. However, he still considers the forwarding of the utilization of wind power as a principal interest.

It may be added that at the present time the chief obstacle to the early utilization of wind power is the lack of a prototype aerogenerator, that is, a full sized operating unit, wind turbine and electric generator, complete, together with adequate field tests. Outside of the staffs of the Federal Power Commission and the Bureau of Reclamation there are very few, if any, designing and construction engineers familiar enough with the wholly unique characteristics of aerogenerators to undertake an installation without a disturbing amount of special research work, for which they are not equipped. However, with such a complete prototype and tests, design and installation could be undertaken in quantity, and at close to minimum cost. Such a protype would pay its way in service in the system in which it was located.

I wanted to give an idea of what one of these larger generators would look like, and without having one that was a dilemma so the Commission built a little model to give an idea what one design would look like, and we used that model to make a picture as to how a generator would look in the service, primarily on a hillside or a hilly country where the wind would be strong and we would get a rather magnificent height, because to get the wind effectively you have got to go where the wind is, which is up in the air. The lightness of the construction and yet the great stability coming from the wide base, and simplicity of the wind wheels, shows why it is possible to make these units at a reasonable cost.

If any of you get to look at it afterward, we have two or three models of parts of this proposed generator. Here is the wheel [indicating]. That is one blade. We have a number of papers here, Mr. Putnam's book on the subject of wind power, and some other papers here, if you care to look at them.

That is all I have in my statement, but more might be said if you care to ask any questions.

The CHAIRMAN. Mr. Farrington might, I think, well begin with questions.

Have you any questions, Mr. Farrington?

Mr. FARRINGTON. I have no questions.

The CHAIRMAN. Mr. Budge.

Mr. BUDGE. I was wondering why something of this kind has not been developed in the past. I did not get your reasons for it.

Mr. THOMAS. Efforts have been made in many places. You heard Mr. Warne speak of the Russians, the English, and others, as well as in this country. One of the big projects was a plant that cost over a million dollars that tried to use the rotating cylinders for ship navigation and failed.

The point is this, that until recently the only principle on which you can operate a wind turbine efficiently as against steam operation has only just been discovered. It is a matter of two or three times as effective. I don't think you want me to be technical but I can give you very briefly the essential new facts.

We are dealing with the wind, which has no resistance. We pass through the air, and we do not notice it. That makes it difficult to get power, either into the wind or out of it. If you take your hand and slap a surface of water very gently your hand goes through without much trouble, but you slap it hard and the water resists as though you hit a slab of marble, and if you hit it hard enough you will injure yourself seriously. In using wind the blades have to go with such enormous speed that, in effect, they slap the air with a terrific impact. That is an intermittent impact. You cannot keep hitting the same bit of air very hard time after time, it disappears, so if you have got a current of air you have to wait after one blow for the current to become reestablished. That is an intermittent impact. You can see that in the airplane propeller which turns at an enormous speed. As the blades go through the air the air has a chance to go through between blades and become normal again. Nobody has apparently understood how to use that in a wind turbine because nobody with that particular information ever tried this until recently through research with the airplane propeller. This is the new realization of how to get something into and out of the air that makes it possible to offer an economic wind turbine.

The CHAIRMAN. Have you finished, Mr. Budge?

Mr. BUDGE. I would like to say, Mr. Chairman, that this would certainly be a wonderful thing if it works.

The CHAIRMAN. Any questions, Mr. McMullen?

Mr. MCMULLEN. I believe not.

The CHAIRMAN. Mr. Aandahl.

Mr. AANDAHL. How long do you propose those blades should be on the wind turbine?

Mr. THOMAS. From here to here [indicating] is 75 feet. As I say, that is a 200-foot circle in which that rotates. You would use

the term "wind charger." The wind charger looks a little like that, but it is a small diameter wheel and it is not feasible to make an efficient design that can be used in the turbine.

Mr. AANDAHL. Do you anticipate any difficulty in storm periods with that structure in the air?

Mr. THOMAS. No, this design would stand up in a hurricane, a 200 or 225 miles per hour wind. It is not a difficult problem. You see, there is a very wide base [referring to model] very stable, and these members are all heavy steel, they expose almost no surface to the wind. It is not like the side of the house. The wind flows through and between. There is no difficulty in making it withstand any wind pressure.

The CHAIRMAN. Mr. Yorty.

Mr. YORTY. I feel just like Mr. Budge, Mr. Chairman. The possibilities are so attractive I do not see how we can afford not to use them.

The CHAIRMAN. Mr. Saylor.

Mr. SAYLOR. Could you explain to us the principle upon which something of that size would begin to move? With any normal wind, or any small wind, to me it seems rather doubtful whether or not it would turn. What wind velocity will you have to have to start to move them?

Mr. THOMAS. Well, I have, for my own interest, and in order that it may be useful to other people, studied this matter in every detail, as to how it could be used in systems, and if I were operating the system how I would care for it, and my conclusion is, in general, there are no special conditions. It would be normal to have the windmill going all the time, whether there is wind or not. It has automatically a strong stabilizing effect on the transmission line to which it is connected. It is the equivalent of what is called a synchronous condenser sometimes installed on the end of the line to support it. You might say at times there is not enough natural wind energy and the scheme which I have is such that when it slows down to the point that the energy is not enough to rotate it we could keep it rotating from any energy produced by other turbines. The energy that is used to keep it going in the system is very small, but by keeping it going we have the stabilizing effect on the system at all times. That is my own special system that I have worked out as to the way I would operate it in a system.

The CHAIRMAN. Judge Fine, have you any questions?

Mr. FINE. I was so intrigued by the gentleman this morning that I skipped another subcommittee meeting. I hope it works even with the slight wind that sometimes has kept us indoors here in Washington.

The CHAIRMAN. Have you any questions, Mr. D'Ewart?

Mr. D'EWART. At what scale is that model?

Mr. THOMAS. The height of this point [indicating] is 475 feet. The rotating wheel is 200 feet in diameter. I think the scale came out exactly 360 feet across, about 120 to 90 feet up to this point [indicating]. This covers 80 feet [indicating the generating room to the top]. This is about 50 feet in diameter [indicating diameter of the turntable], 75 feet from the blade.

It is 14 feet wide at the base, about 12 feet wide there [indicating a leg], and it is 280 feet between center lines here.

Ask me any questions and I will give you any of those dimensions.

Mr. D'EWART. What is the maximum speed at the tip of the propellers?

Mr. THOMAS. 550 feet a second. That is about half the speed of an airplane propeller. But we are more interested here in high efficiency than we are in the propeller, so we cut the speed down a little, because it makes it a little more efficient.

Mr. D'EWART. You have a great deal larger propeller, too.

Mr. THOMAS. Very much larger; yes; but we are dealing with a wind that is moving 30 miles an hour, whereas the airplane has to deal with a wind speed of 100 miles an hour.

Mr. D'EWART. Has there been anything like this constructed anywhere in the world?

Mr. THOMAS. This is the only thing which has any resemblance to it. As I read to you, we are taking this [indicating the propeller] and we increased the size of the wheel one-seventh. We increased the width a little, the length a little, and doubled the speed as compared to the Grandpa's Knob wind wheel. We put two rotors on instead of one, and we also have a better shaped wheel. That is why this added efficiency that I spoke of comes in; it comes in the speed and shape of the wheel. We haven't changed the type particularly. We used some engineering sense to eliminate some of the smaller difficulties that we found, and took advantage of some of the known factors.

There have been a good many factors that have added up to a very considerable gain. We do not depend on anything except this Grandpa's Knob aerogenerator and the vast number of research tests made in the wind tunnel. Of course, we rely absolutely on the wind-tunnel tests.

The Russian, French, and Dutch models are interesting, but their efficiency does not compare with what we need. They are all historically worth looking into, but they do not mean much to us. You have got to take this principle of intermittent impact and work from that.

Mr. BUDGE. Mr. Thomas, I notice your model appears to turn with the wind the same way as a windmill does.

Mr. THOMAS. It does. This has got a pin in it that keeps it from rotating. [indicating the turntable].

Mr. BUDGE. You will be able to utilize the wind from any direction?

Mr. THOMAS. Yes. This was not made to show up for operation. This was made to size, but when I get this pin out it will turn. These wheels will turn [indicating]. There is a railroad type turntable there, about 50 feet in diameter. It is like the turntable on draw bridges. In fact, this is about the length of the drawbridges and weighs about the same. It is the same kind of turntable [indicating distance between centers of rotors].

We do not have to go into a research on designs in the mechanical construction. These are structural steel members [indicating], like the Eifel Tower or the Empire Building, or any of these other big structures. Everything is ready for our hands to proceed except the authorization.

The CHAIRMAN. Mr. Aspinall.

Mr. ASPINALL. No questions.

The CHAIRMAN. Mr. Crawford.

Mr. CRAWFORD. Mr. Thomas, does the language on page 43 of "The Wind Power Aerogenerator" apply to this design that you are now showing?

Mr. THOMAS. Page 43?

Mr. CRAWFORD. Page 43, paragraphs 3, 4, 5, and 6.

Mr. THOMAS. "A modified form of wind gusts occurs when the high speed tip of the blade passes very rapidly from a point of low wind velocity to a point of high wind velocity, as can happen in a fraction of a second. This is a hazard more from unbalance of load on the wheel than as an excess pressure. Both contingencies are allowed for in the present design."

That is correct. We have gone into as many of those irregularities, of special conditions as we can.

For your information I will say the electric power transmission people have made a very elaborate study of this question of gustiness in the wind. They set up a framework 600 feet long and perhaps 150 feet high and they set instruments all over the surface which would automatically record the velocity of the wind. Each instrument recorded the wind at that particular spot. Those recordings were all reported and they gave a magnificent pattern showing what occurred at each particular spot.

The wind blows in all directions and at all velocities. We have taken advantage of all such data as that.

Now, take these other points, if, on the other hand, the blade speed increases as a result of the higher wind pressure, destructive thrust pressures will rapidly develop, for the relative velocity will increase at almost the same rate as the blade speed, and the thrust varies as the square."

That is a technical statement. It ties in with the problem of controlling the speed of the windmill. That has always been a problem. The farmers' windmills and wind chargers are controlled perhaps by some of the various devices. We have to do the same thing. We have to get a strong wind to operate regularly. It will run away [indicating the speed of the rotor] if we do not have some way of stopping it. So we have devised a very simple and easy method by which if the wind gets strong the wheels slow down and as they slow down they get inefficient and waste the power that we do not want to use. That is the simplest way of getting rid of the moving parts that they use in most other windmills.

The next paragraph, "Strength calculations are here based upon 10 percent overspeed for the wheel," that is while 52½ revolutions per minute is the stated speed and while we have means to keep it from going any higher, we provide the breaking effect so that the full factor of safety still exists even if it goes up to nearly 60 revolutions per minute. That is a matter of engineering design, and a matter of safety.

Mr. CRAWFORD. I simply wanted you to read that brief statement, to get before us some of the technical problems involved.

Mr. THOMAS. That is the thing to do, to bring everybody's attention to some of the things that are necessary for consideration in this design.

Mr. CRAWFORD. Have you made any rough figures as to the cost of the design?

Mr. THOMAS. Building the complete outfit?

Mr. CRAWFORD. Yes.

Mr. THOMAS. If you look on page 49 you will find a very complete list of the material and estimates of the cost of labor required for this particular model. There was a lot of time put on that, and a lot of attention. Unfortunately it is a little old now and I have used this method of estimating the cost, as far as it is feasible, to estimate the the cost of a thing that has not been built.

Mr. CRAWFORD. You mean pages 49 to 52, inclusive?

Mr. THOMAS. Yes, I think that is it.

Mr. CRAWFORD. The over-all total being $5,000,000?

Mr. THOMAS. That is it. That is for 10 units.

Mr. CRAWFORD. Let me ask you this question: I understand—I want you to correct me if I am in error—that since the failure of the Grandpa's Knob proposition this new principle and design has come into being; is that right?

Mr. THOMAS. Will you state that again?

Mr. CRAWFORD. I say, as I understand the testimony—I want you to correct me—that since the failure of the Grandpa's Knob wind turbine and experiments this new concept and design has come into being.

Mr. THOMAS. I would say "yes" in this sense, the failure was due to what they call material fatigue. You take a copper wire, and keep bending it, after a while it breaks.

Mr. CRAWFORD. I understand.

Mr. THOMAS. There were strains in that blade there in Grandpa's Knob which were higher than the mechanism there could properly be expected to stand [pointing to illustration]. There was a mistake on the part of the engineers who laid it out and they gave wrong figures to the contractor. He built it and discovered this mistake when he was about done, and he said, "It would cost about $100,000 to $150,000 to change that around. Maybe it will go through. Let us try it," and it did go through.

Mr. CRAWFORD. I got the impression there was a change in the design of the blades and the wheel, also.

Mr. THOMAS. There are some radical changes between Grandpa's Knob and ours.

Mr. CRAWFORD. In other words, this has never actually been tested out, such as the equipment used at Grandpa's Knob?

Mr. THOMAS. No. There are mechanical changes which engineers understand. There are experienced engineers who would supply the type of construction with which they are familiar for any change in design which turns out to be pretty difficult mechanically.

Mr. CRAWFORD. I would like to get this in the record. Secretary Warne mentioned it two or three times. It is true, is it not, where corporations A, B, C, and so forth, go out and build pilot plants to develop certain processes, and to establish certain data, they do not think of the cost of the undertaking as related to units, such as they would think of the cost of a new plant as related to units turned out after the experiment is all over with?

Mr. THOMAS. That is universal.

Mr. CRAWFORD. Building pilot plants and experimental work is one thing and operation of a plant which has been correctly designed and built for straight outright production is something entirely different; isn't that true?

Mr. THOMAS. The reason that this Grandpa's Knob cost so much money is because they did not know where to begin. They did a lot of things outside of building the plant, they spent a lot of money that does not have to be spent again.

The CHAIRMAN. If the gentleman will yield, there is an interesting and almost romantic history back of the Grandpa's Knob plant.

Mr. THOMAS. There is.

The CHAIRMAN. A tremendous lot of experimentation went into it. May I ask what caused the blade to come off?

Mr. THOMAS. In the original plan, Mr. Putnam, and the engineers, of course, had this entirely new shape and entirely new set of strains. They did not know what to do. The airplane people said it is very much the same surface as the wing of an airplane, so why not build it like the wing of an airplane. The wing of an airplane made of $\frac{3}{16}$ stock with aluminum covering takes a lot of strain, so why not use the same thing here? They ran into some troubles because you may build 500 wings in airplanes and you pay for special tools, presses, and so forth, and they do not cost so much per wing, but here was one machine and they had the same costs for presses and forms, and it became very burdensome. They did not get the best shape because they could not afford to.

They overlooked another difficulty: In the wing of an airplane the whole round shell fits into the body, and that gives it a stable base. In Grandpa's Knob there isn't any body here for the ring to fit into, it just ends. That was the thing they did not fully realize. They produced a design there, and they did not get it quite strong enough.

I am getting into some technical things.

The CHAIRMAN. This is a technical question I want to ask, and I take the burden of this: An engineer told me the other day about a new alloy that was extremely strong in tensile strength, and all that, and very light. I think it is a very strategic and critical material and I cannot name it. Has there been progress made in new alloys that would probable give promise in such construction?

Mr. THOMAS. I think so. I think we have to look forward to every advantage we can get that way. The importance of a light, strong material in these blades is very great, and we propose to use this duralumin, or something like that. If they get this alloy that you speak of that will be the full answer to this type of device.

The centrifugal force is terrific. The construction of the blades is aluminum and the base is steel. This duralumin I would use for the framing inside, and I made the outside out of wood. I expect to have people object to that, but you have seen beautiful yachts out of the water, and you have seen how the wooden side is sheathed. When you build two or three of those you can build them with wood at a reasonable expense. To get such curve with aluminum you have to spend hundreds of thousands of dollars, and can only afford one or two. That is a detail that will have to be developed. The one I worked out had some great advantage.

Mr. CRAWFORD. You mean the power plant is an experiment?

Mr. THOMAS. Yes, because after we build that one we know what to do next.

Mr. CRAWFORD. Have you been to Europe and visited these spots where they had experiments?

Mr. THOMAS. I have been in Europe but I haven't seen those. I am familiar enough with what is going on to make this statement: Anybody that has limited time and effort to spend on wind turbines could better spend it studying Grandpa's Knob, and what we have got here. This idea of intermittent impact, and some of these other features have outmoded all these other lines of experiment that just do not have any direct bearing on making an economic wind turbine. It is something that has only been possible very recently.

Mrs. BOSONE. Mr. Chairman, may I say when I see a person like Mr. Thomas, in the ardent pursuit of this scientific idea, I have a heart full of gratitude. I just wish we had more people like him, because I believe the world progresses because we have this type of man. I can well understand why the two departments of the Government, and this committee, are interested in this project because we look twice when we see the honesty, humility, and scientific brain, and the patriotic pursuits of the scientific idea, such as demonstrated by Mr. Thomas. This is probably the greatest asset for the whole idea.

The CHAIRMAN. I think I ought to remark to Mr. Thomas that is a finer compliment than he knows. The lady is a big-hearted lady in every respect, but to combine it with intelligence and appreciation is the maximum compliment.

Mr. THOMAS. I shall not try to express my appreciation, but I would like to say this, that I am glad I have had the opportunity to work on a thing of this kind, which is wide open. This thing happens once in a generation, and to be allowed to work on it is a very great pleasure. It carries its own reward, you may be sure.

Mr. ENGLE. Where is the generator?

Mr. THOMAS. Inside of the house here [indicating]. Here is an artist's picture of how the generator would look. You see, that is a good-sized room that is on top of the 50-foot turntable. You see the generator, rotary converter, and transformer in there, the batteries, and other things that go with it.

Mr. ENGLE. You have a direct connection from the blades to the generator; is that right?

Mr. THOMAS. This turns around and there is a big gear inside and a shaft runs along and enters here [indicating], and the generator sets right in front. If you were here you could see it.

There is a bit of shaft there [indicating].

Mr. ENGLE. Both propellers are connected with the same generator?

Mr. THOMAS. It can be either way. For experimental purposes it might be well to have tow generators and then one could run without the other.

Mr. ENGLE. How would you synchronize them?

Mr. THOMAS. As you synchronize any other generators. They have automatic synchronizers. You could operate them together with one switch open and connect the sychcronizing apparatus, and when they get in the right position then automatically the switch closes and they run together.

Mr. ENGLE. You discussed this principle of intermittent impact. I can see how that applies to an airplane propeller running through the air, where you have a power-driven propeller but here the thing is the reverse, the wind makes the impact on the propeller.

Mr. THOMAS. That works the same way. In the airplane propeller the downwind cut is giving an impulse forward, but on the other side there is a vacuum and air gives the impulse the other way. In the turbine there is a positive and negative impulse, one on one side and one on the other. We do not know which way they are operating. The pressure is on one side of the propeller and on the other side in the turbine. There is pressure on one side in the air and suction on the other. The two things are quite interchangeable. It is a matter of physical stresses, in that sort of thing.

Mr. ENGLE. I don't know as I understand it.

Mr. THOMAS. Would you repeat your question?

Mr. FINE. You are cross-examining, and I am trying to find out what he is saying.

Mr. ENGLE. I am just intrigued with the idea that there is a new concept to this thing. I take it these farmers' wheels that we see running their pumps, which is pretty much of a solid wheel with a number of spokes on the propeller, is a very inefficient device, isn't it?

Mr. THOMAS. No, they run on the same principle, but they are not driven at a very high speed. They do not carry to the limit. They are small, and a lot of considerations have to be taken into consideration. The costs are not so important. They do not care whether it is 10 cents a kilowatt-hour or one-half cent, they just drive it for water or light.

Mr. ENGLE. I want to ask one more question. If you have a steady wind, Mr. Thomas, do you still say that you have this business of the intermittent impact? Let us assume you have a steady 30-mile wind running across the propeller, does your theory of intermittent impact still work?

Mr. THOMAS. There is this big circle here [indicating] in which these blades rotate, This is one instance of time, and this is the blade there [indicating]. The push of the wind that blows through between the blades blows through without any hindrance, at the normal speed of, say, 30 miles an hour. But let my finger represent one little filament of the wind, this starts to move and run across the wind and that particular filament has to stop. It is blocked, and stopping it gives it a terrific shock, but the blade runs on by. The wind can then start and get going again, the oncoming pressure speeds it up. That particular filament of wind started and stopped with a shock, and the blade gets a shock from every new filament that it gets. The blade has a constant pressure because it is always cutting the wind, or some filament of the wind. It is intermittent within the circle. You have got to consider the wind made up like a sheaf of straw from wheat running parallel. Each wind has its own momentum, and each wind produces its own force. When the blade hits it that is where the intermittent impact comes in. You can't see it but people realize that is what is going on.

Mr. ENGLE. Thank you very much.

Mr. THOMAS. May I volunteer one question?

The CHAIRMAN. Yes, Mr. Thomas.

Mr. THOMAS. The question was raised about using a windmill to pump water in the Navajo Reservation. You are satisfied to pump water when the wind blows and store it, if you like. You do not need any electrical machinery. It greatly simplifies and considerably

reduces the cost of a windmill for that particular purpose. It works out nicely for merely pumping water when you have sufficient wind.

The CHAIRMAN. Our time has expired. Some of my questions are yet unanswered, but we will forego them.

I want to thank you, Mr. Thomas, sincerely for myself, and for the members of the committee for this splendid testimony. The ends have not been reached in our scientific research, but we are making progress all the time.

I never was in favor of declaring a moratorium on inventions, or a holiday on scientific discoveries. It was proposed in Congress 10 years ago that we do that, and I think had it been done then we would not have this idea. We thank you.

It was not my purpose to take action on the bill today, but merely to get the testimony, and in order to round out the testimony I had invited a gentleman to come. We will now hear him. We have with us to day Mr. Wesley H. Rudisill, who is also an inventor, and has his ideas, too, of a little different application, no doubt.

Mr. Rudisill, will you please come forward.

We thank you for coming today. You may proceed with your testimony.

STATEMENT OF W. H. RUDISILL, ENGINEER, SILVER SPRING, MD.

My name is Wesley Haven Rudisill, and I reside at 2408 Colston Drive, Silver Spring, Md. I am an engineer and have spent practically all my adult life in the public-utility field, largely in the engineering branch.

After graduating from Bliss Electrical School in 1903, I was engaged 8 years in line- and power-house construction work and in power plant operation. In 1911, I was made chief engineer for the gas and electric properties in Alabama owned by the Electric Bond & Share Co. After 2 years in that position, I became chief engineer for the electric properties of the H. H. Rogers estate which are now the Staten Island Edison and the Jersey Central companies. I held that position for about 10 years.

In 1922, I went to Manila, Philippine Islands, to conduct studies of the plant requirements of the Manila Electric Co. and to take charge of all engineering and operating activities for that company. In 1926, I returned to the States, becoming vice president of the Chester Valley Electric Co. which is now a part of the Philadelphia Electric system. I served about 8 years in that position.

From 1933 to 1938 I was engaged as a consulting and contracting engineer, chiefly in connection with heating and boiler-room design and construction. Since then I have been an engineer analyst with the United States Securities and Exchange Commission here in Washington, where I am still employed.

In the course of my experience I have been in full charge of the operation of steam- and hydro-power plants, transmission, and distribution systems and have designed, revamped, and built power plants and electric systems and have inspected, appraised, and analyzed the performance of many such plants and systems.

I became an associate member of the American Institute of Electrical Engineers in 1909 and was made a member of that institute in 1926. I hold professional engineers' licenses in the Philippines and in Pennsylvania and for 3 years was chairman of the board for licensing electrical engineers in the Philippines. While residing in New York, I held steam engineering licenses for New York and New Jersey.

About 15 years ago I became interested in the possibilities of large-scale generation of electric energy from wind power and began to spend much time in study and research on that subject. Satisfactory solutions of many of the problems encountered were difficult and baffling.

Winds that are generally available have comparatively low velocity and the energy content per square foot of area of such winds is low. As a result, the generation of large blocks of power from them requires huge machines, and it was difficult to find a design that would keep their unit cost comparable with those of other types of prime movers. In addition, regulation of wind driven machines is difficult because they must operate through wide ranges of wind conditions and must stand up under hurricanes.

To be economically sound and able to compete with other types of power plants, wind plants must produce energy at lower costs per kilowatt hour than any other type of plant. Such costs must include not only operating costs (which are very low for wind units) but all fixed charges such as interest on the investment, depreciation, taxes, etc.

To be successful a wind-driven plant must be entirely automatic, rugged, dependable, and efficient, especially under low-wind velocities.

After several years, I developed a design that met these requirements and applied for patent coverage thereon.

I designed and built a working model and equipped a laboratory to determine the capacity, efficiency, and behavior of a machine built on my design. Hundreds of tests were made and experiments with blades of different size, shape, setting, and number were conducted with highly satisfactory results. About a year ago, the patent was issued (U. S. Patent No. 2517135).

In the interval between the time I first began to study the subject and the present, conditions have been increasingly more favorable for wind generation. Production costs for fuel-burning plants have increased sharply due to price advances in fuel, transportation, labor, and supplies. The fantastic development of the airplane has made available a mass of data on the dynamics of air flow which was unknown a decade or so before.

The unit cost of building fuel power plants had doubled, and good sites for hydro development—sites with worthwhile stream flow and within economical transmission distance of markets—have become very scarce and expensive.

Hydro shares with wind power the great advantage of having no fuel cost, but its output suffers in years of drought, while a wind-power plant can be depended upon to produce practically the same number of kilowatt-hours every year as shown by Percy Thomas, one of our Nation's foremost electrical engineers and a witness at this hearing. Furthermore, hydro is now severely handicapped because of increased development costs (now often two or three times the cost of steam capacity and several times that of wind capacity).

About 1941, the S. Morgan Smith Co. decided to build a wind-driven unit following the ideas of Palmer Putnam, about whom both Mr. Warne and Mr. Thomas have testified. Some of the Nation's foremost scientists and engineers were enlisted for its design. The machine was built and operated. Although a mechanical failure finally put it out of commission, its performance proved the practicability of large-scale wind generation and gave its sponsors the data they had set out to secure.

During the period when this Smith-Putnam project was active, Thomas was making his exhaustive and valuable studies of the possibilities of wind power and of wind dynamics. In 1946, Thomas issued another report describing two designs which he had worked out for large wind-driven units and which, through the ingenious usage of electrical equipment, seem to overcome some of the regulating difficulties of the Smith-Putnam unit. I might point out here that the Smith-Putnam and the Thomas designs are propeller type, using only two very long wide blades (in the second Thomas design, three such blades), while my unit is a true impulse-type turbine using a large number of short, narrow blades, larger but similar in appearance to the low pressure blades of a large stream turbine.

We owe a great debt to Thomas for his studies and to the men behind the Smith-Putnam project for pointing out the great possibilities of wind power.

Other nations too have been working in this direction. Russia, about 2 years ago, announced that it had a program to build immediately a hundred or more wind-driven units, but the "iron curtain" has prevented us from getting any specific details about it. Britain and France for several years have each had committees of scientists and engineers working to develop means for using the wind, and just lately they have pooled the work of such committees.

I am firmly convinced that the time has come when there is available here in the United States, the "know how" to build practical and dependable wind-driven power plants that will produce great blocks of electric energy at lower cost (including all fixed charges) than can be had from any other type of plant.

I know that our country badly needs this energy in its defense effort. I know that the preparation and transportation of fuel to run our steam plants requires valuable man power.

This bill H. R. 4286, by permitting the Bureau of Reclamation to contract for the building of a wind-driven plant, would give that Bureau a supply of low-cost electric energy which it badly needs and which would supplement its hydro output in a most practical way and would also demonstrate the feasability of wind generation. At the same time, the effect of H. R. 4286 would be to conserve our natural resources of coal, oil, and gas.

In the drought-stricken Northwest, power is now so scarce that the Government as a defense measure may require some of the aluminum plants in that area to move to other locations.

If a pilot wind-driven plant can be installed quickly enough it can point the way to a far more economic solution of the power shortage than moving these huge aluminum plants. Requiring minimum amounts of structural and plate steel which make up most of the materials needed in wind units, a hundred wind-driven power plants could be built in a few months—probably in less time than moving the aluminum plants would require.

In my opinion, the Interior Department has a strong staff of engineers fully qualified to pick out the most suitable design of machine available for its purposes.

In the West, where the unit would be installed, especially favorable wind conditions exist which make the project particularly attractive and sound.

Under the present conditions, public-utility companies and manufacturers, which normally would be competing among themselves to develop this line of equipment, are so busy trying to meet the demands on their plants that they do not have the manpower to produce a demonstration unit. Unless this bill goes through, I am afraid the great benefits of wind power will be lost for some time to come. If the bill is passed, I believe the next 2 or 3 years will see the erection of thousands of kilowatts of capacity in wind-driven power plants.

I have been asked to describe my invention (the deflector wind turbine) and and to tell how it differs from the conventional or propeller type. Attached hereto are two folders briefly descriptive of my invention.

Will you imagine a wheel 160 feet in diameter mounted on a horizontal shaft carried in roller bearings between two tall pedestals? Upon the rim of this wheel are mounted 60 blades, each 10 feet long and approximately a foot wide. The front end of the shaft is geared to an electric generator capable of carrying a 3,750-kilowatt load.

In front of the wheel an inner deflector or cone is mounted in such a way that its apex points into the wind and its base just covers the wheel itself. It thus deflects outward onto the blades all the wind that would normally strike this inner part of a propeller where it would do very little work. The outer deflector, a funnel-like device 200 feet in diameter at its front or windward edge and 180 feet in diameter at its smaller rear end, is held in position in front of the wheel so as to gather in some wind that would normally pass beyond the blades and turn it into the blades. This outer deflector is held in position by a structural steel arch mounted on two structural steel towers, which in turn are mounted on a platform that can be moved forward into the wind or back to its normal position by motor-driven jackscrews when regulation requires it.

These two deflectors, so mounted, turn all the wind intercepted within the circle of the outer deflector and concentrate it upon the blades of the unit through the throat or orifice formed by the two deflectors immediately in front of the blades. The area of the orifice will be from one-fifth to one-fourth the total area of the great circle of the outer deflector (depending on the conditions which the particular wheel is designed to meet), and by its venturi effect theoretically will increase the velocity of the wind through the orifice to four or five times its original velocity. The law of the cube, one of the most important physical laws of wind dynamics, states that the energy in the wind varies as the cube of its velocity. Since the deflectors theoretically have increased the velocity of the wind to 4 or 5 times its original velocity, its energy theoretically will be increased 64 or more times. I say "theoretically" because some of the energy in the wind is wasted by impingement and friction against the surfaces of the deflectors, but nevertheless the velocity is increased materially, just how much depending on the angles of deflection.[1]

In addition, these deflectors serve another important office, namely, regulation. The machine is so designed that with low and normal wind velocity all the wind is concentrated on the blades, but with "over winds" (that is, winds that would develop more energy than the generator can safely carry) the throat or orifice chokes up and spills all excess over the rim of the outer deflector. Thus, without resorting to any feathering or coning of the blades, the deflector unit has practically "inbuilt" regulation. Under very high wind velocities, however, some slight amount of added regulation is needed, which is accomplished by moving the outer deflector forward into the wind, thereby increasing the throat or orifice area and allowing some of the wind to spread out beyond the blade tips. This same "spill over" feature smooths out and virtually eliminates the effects of gustiness, which makes the regulation of the propeller-type units so difficult.

[1] The deflectors cannot change the energy content of the 200-foot diameter area but do greatly increase the efficiency of the blades onto which the deflectors turn the wind.

One or more of the units just described (depending on the total capacity desired) would be mounted on a turntable automatically controlled to keep the units pointed into the wind or in any other desired direction. The deflector-type unit is completely automatic but always under complete supervisory control of the system-load dispatcher, who may be located many miles away. It requires only periodic inspection and attention.

High efficiency, ruggedness, and low construction cost give my machine the ability to produce lower cost electric energy than can be produced by any other prime mover. It has been said that efficiency in a wind unit of itself means nothing, because wind is free, but this is a mistake. A unit that has a 60-percent efficiency, when compared with a unit having the same wind-swept area but only 30-percent efficiency, will produce more than twice as much energy as the less efficient unit. Or conversely, a unit having 60-percent efficiency but which is only half the size of a unit with 30-percent efficiency will produce more energy than the larger but less efficient unit. This means that the more efficient unit will cost only about half as much to build; and since fixed charges are the principal cost of operating a wind unit, the kilowatt-hour cost will be about one-half that of the lower efficiency unit.

The remarkably high efficiency of the deflector wind turbine springs from four sources, each in itself of significant value but when combined multiply the effects of each other. My definition of wind-wheel efficiency, to which I do not believe anyone will take exception, is the ratio of the energy delivered by the unit to the total energy contained in the wind-swept area of the machine.

One of the sources of my unit's efficiency has been described already, namely, the deflector action which concentrates the wind on the blades well away from the wheel center and increases the wind velocity acting on the blades. An important factor in producing efficiency is the total length of leading blade edge. When the blade of a wind wheel cuts into a wind stream, the mass velocity impact due to suddenly stopping that wind stream is very considerable. After this impact and until the blade has moved all the way across that particular wind stream, a wedge of dense air forms in front of the blade which has a tendency to split the wind stream and lessen its pressure on the blade. The narrower the blade, the narrower the dense air wedge will be and the greater the blade efficiency. Four blades each 1 foot wide will develop more power than two similar blades each 2 feet wide. The deflector unit here under consideration has 60 blades each 10 feet long, giving a total leading edge-length of 600 feet; whereas, in a propeller-type unit of the same wind sweep, the leading edge total is about 140 feet for a two-blade wheel and 210 feet for a three-blade wheel. Each of the propellers is about 14 feet wide as compared with a blade width of 1 foot for the deflector unit. The deflector unit has a speed from 2½ to 5 times that of the propeller unit, which means that each of its 60 blades will cut 2½ to 5 times as many unit wind streams as do each of the two- or three-propeller unit blades.

I believe that with its low construction cost, its high efficiency, its simple and rugged regulation, the deflector wind turbine makes wind generation of electric energy economically sound.

Much has been said at this hearing about the cost of building wind-driven power plants. Each such plant would be designed for some particular location and the conditions that exist there. Kelvin's Law of Diminishing Returns will govern the design. For example, with my design I find that at today's price levels for labor and welded structural and plate steel, which make up the bulk of the material required, a machine with a diameter of 200 feet will cost less per square foot of wind-swept area than a similar machine whose diameter is either greater or less than 200 feet. All machines would be designed to operate at wind velocities from 15 to 60 miles per hour and stand up under hurricane conditions.

At 60-percent efficiency the output of a 200-foot diameter machine would be approximately:

For a wind velocity of—	*Kilowatts*
10 miles per hour	100
20 miles per hour	800
30 miles per hour	2, 700
40 miles per hour	6, 400
60 miles per hour	21, 600

If at the location chosen for our installation, winds of over 20 miles per hour seldom occur except during hurricanes (when the unit will be turned out of the wind), it is obvious that we should not install a generator larger than 800 kilowatts, and that large, only if our annual wind-duration curves show a sufficiently high number of hours' operation at such load. This is in spite of the fact that our main

structure is heavy enough to carry and drive a 21,600-kilowatt generator. Practically the only difference in the total cost between an 800-kilowatt and a 21,600-kilowatt unit is the difference in the cost of the generators, gears, and shafting of the two units. The cost of the main structure, foundations, etc., is identical.

Roughly, any 200-foot diameter deflector-unit structure will cost $170,000, excluding the generator and shafting. An 800-kilowatt generator with its gear and shafting will cost approximately $14,400, making the cost of the whole machine $184,400, or $230 per kilowatt.

On the other hand, if we had a location where the wind-duration curve indicated a 40-mile-per-hour wind velocity for enough hours of the year to warrant a 6,400-kilowatt generator, our total cost would be about $266,000, or $42 per kilowatt. This wide difference ($42 to $230 per kilowatt) shows how difficult it is in general terms to talk about the cost per kilowatt of capacity for a wind-driven power plant. My calculations indicate that a 200-foot diameter deflector turbine will require about 200 tons of welded structural and plate steel, which at today's prices should not cost over $0.20 per pound when erected, or $80,000 for the structure.

All other items excluding the generator, gears, etc., would run the cost up to approximately $170,000. Assuming our wind-duration curve to show the economic size of the generator to be 3,750 kilowatts, the total cost including the generator would be approximately $257,000, or about $68.50 per kilowatt.

To get a 7,500-kilowatt unit we would mount two of the 3,750-kilowatt-equipped machines on one turntable at a cost of about $513,000. This figure does not include the cost of land, transmission line, transformers, or the supervisory control system. Nor does it include the cost of the special engineering which would be required for each individual site where an installation is seriously considered. One big item of cost that applies to the first installation is for research and design. Another item of cost not considered, which may be of small or great moment, is "for improvement of the terrain" around the site of the installation. Cutting down trees and smoothing off hilltops and rough places around the installation can often produce increased wind velocities that will result in much higher output for the unit. Personally, I feel that the estimate of the cost of the project called for in this bill, as forecast by Mr. Warne in his testimony, is well on the high side. I feel that the Bureau of Reclamation will find much less research necessary than it anticipates. The same applies to the actual labor and materials cost for the pilot unit.

In conclusion, I will repeat my former statement that I am convinced that the time has arrived when we can build practical and dependable wind-driven power plants that will produce energy at lower cost than from any other source.

The CHAIRMAN. Thank you kindly. At this point I would like to have inserted in the record, a letter from the Jacobs Wind Electric Co., Inc., of Minneapolis, Minn.

The letter is as follows:

THE JACOBS WIND ELECTRIC CO., INC.,
Minneapolis 11, Minn., October 5, 1951.

MR. JOHN R. MURDOCK,
Congressional Representative (Arizona),
Washington, D. C.

DEAR MR. MURDOCK: It has recently come to our attention that you are sponsoring a bill to finance experimental development of a wind-electric plant, and we are very much interested in the contemplated kilowatt-hour rated output and the wind velocity necessary to secure this output, of the experimental machine designed by Percy H. Thomas. Could you supply us with the estimated kilowatt output in a 20-mile per hour wind of the plant Mr. Thomas proposes—giving also the propeller diameter.

The reason we are interested is that our company is the oldest and leading manufacturer of wind-electric plants in the world, having started engineering and development work on wind-electric plants in 1922, and we now have many thousands of our plants operating in almost every spot on earth. Our oldest production models have been operating nearly 25 years. We supplied the 110-volt plant that furnished electricity for Admiral Byrd's Arctic expedition in 1933, and which was in perfect condition 13 years later, when Admiral Byrd again returned to the Antarctic.

We are enclosing literature which describes briefly the construction and type of our plant. The circular enclosed refers mainly to the d. c.-type, designed for farm and ranch lighting purposes. However, we have done experimental engi-

neering on larger wheels, and are currently doing development work on an a.c.-type of synchronous generator, designed as supplementary power for a. c. high-line current: We have followed very closely all the development and engineering work in the past few years on experimental models, such as the one tried out on Mount Washington, that was wrecked in a windstorm, and other developments of a similar nature in Europe.

We have patented and produced a type of variable pitch propeller blade control which has proven to be far more accurate and positive in its speed regulation an in the prevention of windstorm damage to the plant and equipment than any other wind-electric plant governing system ever developed. Our plants automatically change the pitch of the propeller to relieve the terrific wind pressure which would otherwise be applied against the propeller blades, damaging them, in high winds and storms. Our plants have withstood every hurricane and storm that has hit the West Indies in recent years; and in our own city of Minneapolis two of our test plants, operating continuously, withstood the more than 100 mile per hour winds which struck this city in July of this year. I recently returned from South America and stopped at various West Indies points where hurricane winds up to 135 miles per hour in past years have subjected our plants operating on the various islands to severe wind pressures. No plant has been blown down down from these storms.

Our plants in the small sizes that we build are at present operating on airway beacons, lighthouse service, and protecting many thousands of miles of pipelines in this and foreign countries, through a system of corrosion prevention known as cathodic protection, and whever average wind conditions prevail, our wind-electric plants are protecting America's pipelines, by keeping them charged with d. c. negative potential.

We would like to point out the possibility of also having developed 5-kilowatt a. c. generators, mounted on 75-foot towers, and considerable numbers of them distributed over large areas, so that some of them will be producing current all the time. For instance, 5-kilowatt generators could be produced, with a 60 or 70-foot tower, for a cost of from $1,000 to $1,500 each, which on the bases of $1,000 each would have a rated capacity of 5,000 kilowatts per $100,000 investment, and the entire investment would not be subject to storm damage in case of a single tornado, and at no time would all of the generating plants be idle. The idea we have been working on for some time is to take a line, for instance, from Minneapolis to Great Falls, Mont., and install a series of these 5-kilowatt plants at several mile intervals, which could be directly connected into existing power lines, as boosters, and secure maximum monthly kilowatt-hour output per dollar of building and installation cost. No additional special transmission lines or other extra cost would have to be added.

Frankly, we are interested in the development of this type of plant, because our regular farm lighting business in the past 5 years has been drastically reduced through the building of rural REA lines in the Western States, and we believe there is a need and practical field for utilizing the tremendous and unlimited power of the wind, as supplementary power to generate current for highlines through the widespread installation of wind-driven booster plants, which we believe should be installed along existing high lines at frequent intervals. Thus their output would not unbalance any particular power circuits to which they may be attached.

We are giving you the above general details for your information, and would appreciate hearing from you regarding the possible development and use also of supplementary wind-electric plants along the lines we have suggested, because we believe there is a field for also developing the widely spread, quantity use of small wind-driven high-line booster plants.

We will appreciate your views, and look forward to your reply.

Yours very truly,

M. L. JACOBS, *General Manager.*

The CHAIRMAN. The committee stands adjourned at the call of the Chair.

(Whereupon, at 12 noon the committee adjourned.)

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